PLANTERS' RECORD

VOL. XXXVIII

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THE HAWAIIAN PLANTERS' RECORD

VOL. XXXVIII

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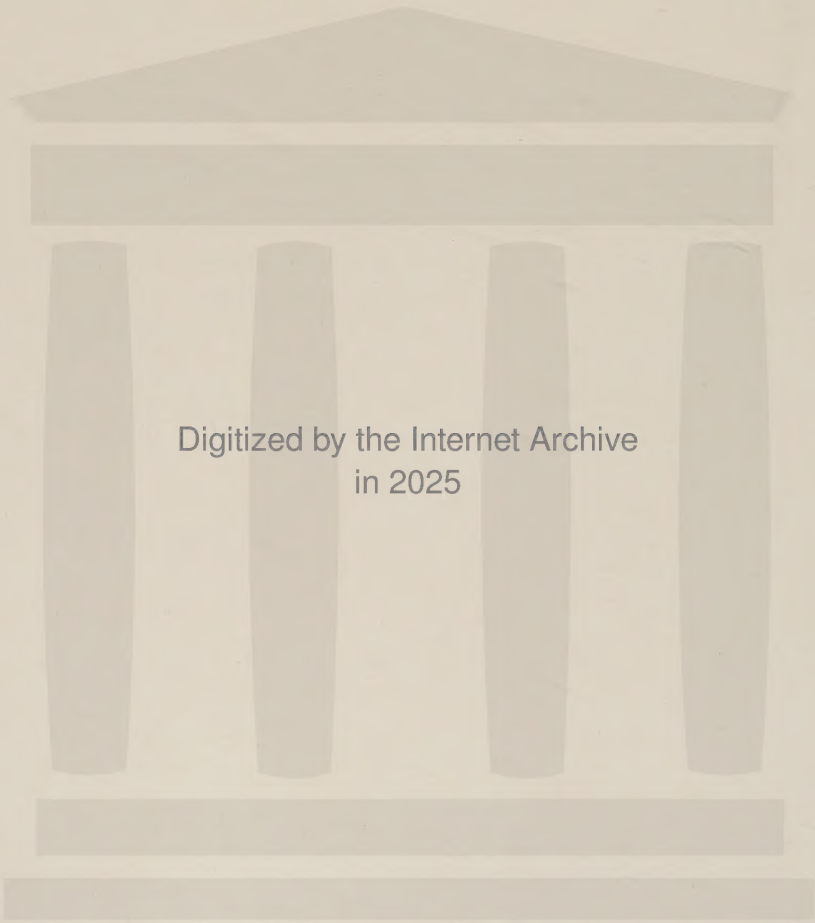
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THE HAWAIIAN
PLANTERS' RECORD

Vol. XXXVIII FIRST QUARTER, 1934 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

This number of the *Record* is devoted mainly to articles reporting studies designed to give us more detailed knowledge about sugar cane. The nutritional work now reported are primary investigations giving basic information on the mineral requirements of the cane plant, and showing the consequences upon the plant growth and structure where deficiencies are brought about under the controlled conditions of the investigations.

Another article deals with the plant under normal conditions of growth and records in great detail the performance in growth and sugar storage of normal cane under normal field conditions.

Such studies as these are necessary as the foundation structure for much that can follow in the field of plant physiology as applied to sugar cane, and ultimately in the field of sugar cane agriculture based on a better knowledge of the physiologic processes of the plant with which it deals. The articles may be more fully described as follows:

Symptoms of Nutritional Deficiencies in Sugar Cane:

The growth of sugar cane, like many other plants, may be studied to advantage in culture solutions. A nutrient solution, which contained the elements essential for plant growth, and which proved to be favorable for normal cane development was used. The methods employed for growing sugar cane plants in the culture solution are set forth.

The deficiency symptoms as manifested by the cane plant when nitrogen, iron, phosphorus, sulphur, manganese, potassium, calcium, or magnesium is omitted from the complete nutrient solution are described and illustrated. These symptoms which proved to be typical for each element may serve to distinguish similar deficiency symptoms should they appear on sugar cane grown under field conditions.

A brief account of the function of each of the eight elements in relation to plant metabolism is given.

The Sugar Cane Plant: A study of millable cane and sucrose formation.

This study was begun in March, 1931. It has important bearing upon the broad issue of cane quality, and questions of its improvement.

The study makes amply clear that for a full understanding of crop yields all the interrelated factors of field culture and of the plant itself must be properly evaluated.

Ripening it is shown is not to be considered to take place in the crop as a somewhat separate plant function from the formation of the millable cane stalk. Ripening is a continuous process taking place throughout the entire life of the plant. It is a joint by joint process. By the time the leaf attached to a joint has dried up and fallen off that joint has acquired a sucrose concentration that is close to the best that it will ever have. Under conditions that bring about fast growth, the greater use of its own sugar by the plant tends toward a lower sugar storage.

We are confronted finally with a question of balance between growth and storage, with a combination of quantity of cane and quality of juice that best serves our objective of the most profitable yield of sugar.

Here sugar cane has been studied not as a crop, nor as a plant alone, but a thoroughgoing attempt has been made to follow the process of millable cane formation and sucrose storage in the individual plants or stalks as they occur in the field as component parts of the sugar cane crop.

Boron Deficiency Symptoms in Sugar Cane:

The importance of small amounts of manganese, boron, zinc, copper, etc., to plant growth has been demonstrated in recent years by a number of students. That a minute quantity of these elements is essential for normal growth has been established by growing plants in water or in sand cultures, and in a number of instances, a marked growth response has been secured when such elements have been applied to specific soils.

The severity of many plant diseases has been directly associated with a soil condition that is unfavorable for normal plant development. A better economic control of many of the pathogenic as well as the physiological plant diseases has been effected through an understanding of the nutritional requirements of the individual plant. It is of practical importance to recognize the type of growth manifested by the plant when grown in a medium which lacks an essential element.

In the paper on boron deficiency of sugar cane, a brief review is given of the literature on the importance to plant growth of small amounts of manganese, boron, and zinc.

The deficiency symptoms which develop on cane plants grown in a minus-boron culture solution are described and illustrated. The symptoms of boron deficiency are depressed growth, the development of distorted and chlorotic leaves, and the presence of definite leaf and stalk lesions.

New Varieties of Promise:

Those who are following the new canes 28-1234 and 31-1389 will find interest in an account of some recent tests.

Symptoms of Malnutrition Manifested by the Sugar Cane Plant When Grown in Culture Solutions From Which Certain Essential Elements Are Omitted

By J. P. Martin

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I. Introduction

Growth of plants is recognized by a permanent change in form, which is usually accompanied by an increase in size and weight. For growth, cell division, cell enlargement and cell differentiation are necessary; these cytological changes of the individual cells within the plant can be detected only by microscopic examination of the various plant tissues. The formation of protoplasm, a very highly organized chemical complex found within the plant cell, is of vital importance in relation to growth since such processes as photosynthesis and respiration are operations performed or induced by this chemical complex.

Such factors of environment as moisture, light, temperature and the availability in the soil of those elements essential for plant growth, govern the rate of growth and development of plants. A number of instances might be mentioned where any one of these factors has been the limiting one for normal plant growth. In commercial agriculture certain varieties are superior to others in a given locality, partly because they are better able to tolerate those peculiar conditions brought about by the existing combination of factors.

At one time, ten elements, namely, carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, iron, magnesium and sulphur, were regarded as the only elements essential for plant growth. In recent years it has been demonstrated that the presence of very small amounts of manganese, boron, iodine, zinc, copper and silica are necessary for the normal growth of certain plants.

As a rule, most of the essential elements occur in the soil in sufficient quantities for natural vegetative growth. However, when economic crops are cultivated,

it is usually necessary to apply additional plant nutrients to the soil; the kind and the amount to be supplied depending largely on the fertility of the soil and somewhat on the crop grown.

A deficiency of one or more of the essential elements in the soil may be a limiting factor for plant growth. In such cases the plants almost invariably manifest abnormalities of growth which may frequently be recognized as definite leaf or stalk symptoms of malnutrition.

The object of this paper is to describe certain deficiency symptoms artificially produced on sugar cane in culture solutions lacking nitrogen, iron, phosphorus, sulphur, manganese, potassium, magnesium or calcium, so that similar symptoms might more readily be recognized should they appear on sugar cane under field conditions.

The experiments recorded in this paper were carried out in water cultures and similar experiments were repeated in water cultures and in sand cultures. The deficiency symptoms that developed on the plants in all experiments proved to be unique for each of the eight essential elements studied. The first experiments were started August, 1932, while subsequent experiments, with the same object in view, were completed December, 1933. In this paper no attempt has been made to review the literature relevant to nutritional deficiency symptoms artificially produced on plants other than sugar cane.

II. Experimental Procedure

Three representative sugar cane varieties, namely, H 109, P. O. J. 2878 and Yellow Caledonia, were chosen for these experiments. A number of three-eye cuttings of each variety were planted in black volcanic sand and irrigated with tap water. Young shoots, from 12 to 16 inches in height, were carefully cut off from the germinated cuttings and placed in a standard nutrient solution. In most cases roots had developed on the shoots before they were removed from the cuttings. A well developed root system soon became established on the plants in the nutrient solution.

The complete or standard nutrient solution used in these studies was one which was modified from a culture solution used extensively by Dr. C. P. Sideris, Experiment Station, Pineapple Producers' Cooperative Ass'n, Ltd., and proved exceptionally favorable for the growth of sugar cane plants. The chemical composition of this solution is given in Table I, and the parts per million of each element are presented in Table II. The basic solution had a pH value of 5.2, while the pH values of the solutions in the deficiency series ranged from 4.6 to 5.8.

The plants were grown in the complete nutrient solution for six weeks. During this period the plants made an excellent growth and, no doubt, built up a reserve of the various elements before being transferred to the deficiency series. At the end of this time plants of a uniform size of each variety were selected and transferred to nutrient solutions in each of which one of the following elements was omitted: nitrogen, iron, phosphorus, sulphur, manganese, potassium, calcium and magnesium. The chemical composition of the nutrient solution in each deficiency series is also given in Table I. An attempt was made to hold the amount of each element the same in each series (Table II). The growth of the plants in

the eight deficiency series was compared with the growth of plants of similar age which were grown in the standard nutrient solution; the latter will be referred to as the control or check plants.

Distilled water and chemically pure salts were used throughout the experimental work, thus making it possible to study the growth of the plants in different media of a known chemical composition. In the deficiency series the plants were grown in the "absence" of a particular element and, no doubt, the deficiency symptoms, as manifested by the plants, developed more quickly than they would have developed under field conditions. In the fields a deficiency of an essential element frequently occurs but an absence of such an element in the soil is rare.

TABLE –1–

CONCENTRATIONS OF THE CHEMICALLY PURE SALTS PER LITER IN THE NUTRIENT SOLUTIONS.

	Partial Volume Molecular Concentrations															P.P.M.*	
Deficiency Series Elements omitted	KH_2PO_4	$NaH_2PO_4 \cdot H_2O$	KCl	KNO_3	K_2SO_4	$Ca(NO_3)_2 \cdot 4H_2O$	$NaNO_3$	$CaCl_2 \cdot 2H_2O$	NaCl	$CaSO_4 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	$MgCl_2 \cdot 6H_2O$	$Na_2SO_4 \cdot 10H_2O$	H_3BO_3	$Na_2SiO_3 \cdot 9H_2O$	$FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$	$MnSO_4$
Complete Soln.	.001			.003		.003		.004			.001			.00002	.00001	10	.25
Nitrogen	.001				.0015			.0035			.001			.00002	.00001	10	.25
Phosphorus			.001	.003		.003		.004		.001	.001			.00002	.00001	10	.25
Potassium		.001				.003	.003	.004		.001	.001			.00002	.00001	10	.25
Calcium	.001			.003			.006		.002		.001			.00002	.00001	10	.25
Magnesium	.001			.003		.003		.004					.001	.00002	.00001	10	.25
Sulphur	.001			.003		.003		.004				.001		.00002	.00001	10[A]	.25[B]
Manganese	.001			.003		.003		.004			.001			.00002	.00001	10	
Iron	.001			.003		.003		.004			.001			.00002	.00001		.25

Ⓐ Fe from Ferric Citrate. * P.P.M. = parts per million of Fe or Mn. Ⓑ Mn from Manganous Chloride.

TABLE –II–

PARTS PER MILLION OF EACH ELEMENT USED IN EACH OF THE NINE CULTURE SOLUTIONS.

Deficiency Series	N	P	K	Ca	Mg	S	Mn	Fe	Na	Cl	Si	B
Control	126	31	156	280	24	32	.25	10	.23	284	.28	.216
Nitrogen	—	31	156	140	24	80	.25	10	—	249	.28	.216
Phosphorus	126	—	156	320	24	64	.25	10	—	319	.28	.216
Potassium	126	31	—	320	24	64	.25	10	92	284	.28	.216
Calcium	126	31	156	—	24	32	.25	10	184	71	.28	.216
Magnesium	126	31	156	280	—	32	.25	10	46	284	.28	.216
Sulphur	126	31	156	280	24	—	.25	10	—	355	.28	.216
Manganese	126	31	156	280	24	32	—	10	.23	284	.28	.216
Iron	126	31	156	280	24	32	.25	—	.23	284	.28	.216

The containers used for growing the sugar cane plants were one-gallon earthenware jars with glazed inner surfaces. A two-piece cover, made of redwood, fitted over each jar. Each plant was held in an upright position by placing two halves of a large cork around it and then by placing the cork and the plant as a unit tightly into a circular hole in the cover. With this arrangement the plants could easily be adjusted and the root systems readily examined at all times. All experimental work was conducted in a large greenhouse in order to avoid adverse climatic conditions that might interfere with the experiments.

The various nutritional deficiency series, as well as the complete or control series, were started September 22, 1932. At first, the nutrient solutions were changed once a week but, as the plants developed, it was necessary to renew the solutions once every four or five days. On December 12, 1932, a photograph of the plants in each series was taken (Figs. 1, 3, 5, 7, 9, 11, 13, 15 and 17). It will be noted from these photographs that the growth of all plants in each series was fairly uniform. The cane varieties that were grown in the various series are indicated in the photographs. Many of the plants at this time, i. e., at the end of 80 days, manifested definite deficiency symptoms, which are described in detail later.

The plants were allowed to continue to grow in the deficiency series until February 24, 1933, a period of 152 days. On this date one H 109 cane plant in each deficiency series, except the minus-iron series, was transferred to the complete nutrient solution. On April 28, 1933, or after an interval of 216 days, the plants in each series were again photographed (Figs. 2, 4, 6, 8, 10, 12, 14, 16 and 18). The plant on the right in each photograph, except in Fig. 2, shows the rapid

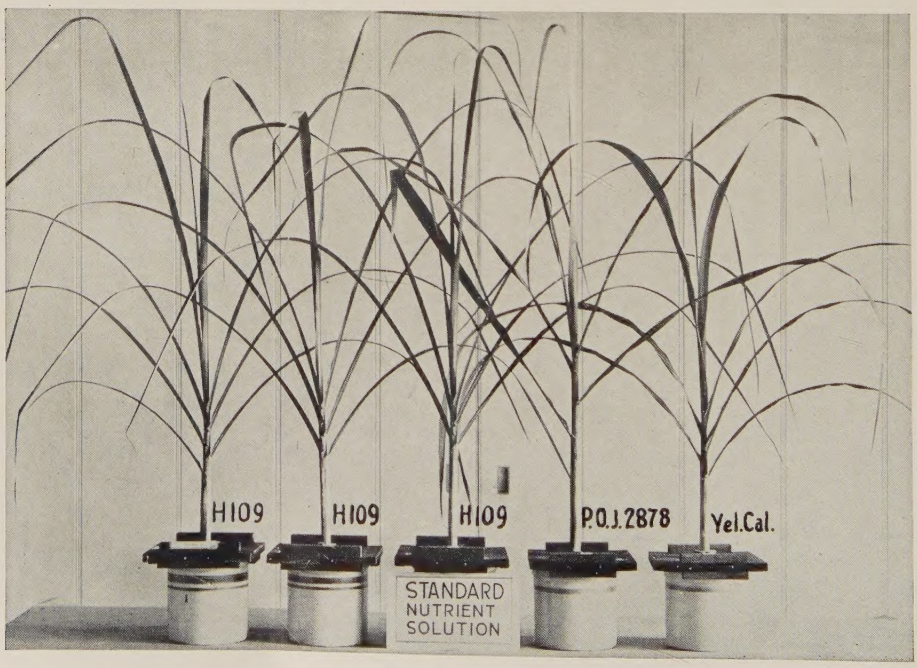


Fig. 1. Control plants, age 80 days. These plants were grown in the complete or standard nutrient solution and appeared normal in every respect.

Fig. 2. Control plants, age 216 days. The plants at all times exhibited a normal color and made a uniform growth. Considerable root injury from *Pythium* root rot occurred, as shown by the reduced root development on the individual plants.

recovery and the normal growth made as a result of the addition of the missing element; the other plants show a markedly depressed growth in contrast to the H 109 plant on the right and to the control plants (Fig. 2).

Shortly before the plants were photographed, April 28, 1933, one or two plants were selected from each series for microchemical tests. These tests showed a deficiency in the tissues of the leaves and stalks of the element lacking in each deficiency series.

A description of the nutritional deficiency symptoms, as manifested by these plants as a result of faulty nutrition, is given under each of the eight elements studied. As already mentioned, the growth of the cane plants in the various deficiency series was at all times compared with the growth of the control plants, which made what was assumed to be a normal growth throughout the experiment (Figs. 1 and 2).

A brief account of the functions of each of the eight elements in relation to plant metabolism is also presented under its respective heading. The information pertaining to the function of each element has been taken largely from publications dealing with plants other than sugar cane but, in general, such information should be applicable to the sugar cane plant. An understanding of the function of an element explains, in a number of cases, why certain symptoms are characteristic of the deficiency of that particular element.

III. Interpretation of Results

Nitrogen

Deficiency Symptoms: In the minus-nitrogen series, the first evidence of any physiological change in the young leaves of the plants was the development of a yellow-green color or chlorosis. This was observed from 2 to 4 weeks after the nitrogen had been omitted from the solution. At the end of 5 to 8 weeks, all leaves were of a uniform pale yellow-green color in contrast to the dark green color of the leaves on the control plants.

The leaf tips and margins of the older leaves began to dry prematurely, the dried portions assuming a light-brown or straw color. The mature leaves died much sooner than leaves of the same age on the control plants. No leaf markings other than this drying of the edges developed.

The growth, or further elongation, of the primary stalks soon came to a standstill. All the leaves appeared as though they had developed from a common point, a definite characteristic of a cane plant that is not growing (Fig. 4). These depressed stalks, or stems, were characterized by being slender and of a light red color. This color change was particularly noticeable on the variety H 109.

The roots appeared to have been stimulated in growth. They attained a much greater length but were smaller in diameter than the roots of the control plants. The root system of each plant completely filled the jar and was extremely free from *Pythium* root rot (Fig. 4).

Upon the addition of nitrogen to the minus-nitrogen series, a definite color and growth response was visible within 15 days (Fig. 4); it may also be observed that the root system of the H 109 plant on the right has lost its compactness fol-

PLATE I

A, B—Nitrogen Deficiency
C, D—Iron Deficiency

lowing the addition of nitrogen. This condition is due largely to the breaking down of the individual roots from *Pythium* root rot. Carpenter (1), in 1928, demonstrated that the severity of *Pythium* root rot on cane varieties grown in the soil increases with increased applications of nitrogen. Of all the deficiency series, the cane plants in the minus-nitrogen series manifested the most rapid recovery when the limiting element was added.

Nitrogen-deficiency symptoms of sugar cane under field conditions in Hawaii have been described by Naquin (14) and in culture solutions in Java by van den Honert (16).

The symptoms of nitrogen deficiency are shown in Figs. 3 and 4 and also in Plate I, where they are shown in color.

The Function of Nitrogen: Nitrogen is one of the constituents of the chlorophyll molecule and its presence is, therefore, essential for the formation of chlorophyll or the green coloring matter in plants. Chlorophyll has the power to combine the carbon dioxide and water within the leaf, utilizing the sun's rays or light energy to form carbohydrates among which are various forms of sugars. This process is known as photosynthesis (a putting together of raw materials by light energy).

Nitrogen combines with carbohydrates to form proteins which, in turn, enter largely into the making of protoplasm. Proteins are complex compounds containing hydrogen, oxygen, nitrogen, sulphur and sometimes phosphorus in addition to carbon. Gelatine and egg white are almost pure proteins. Protoplasm is what might be termed the only living part of the plant and is found within certain

Fig. 3. Minus-nitrogen series, at the end of 80 days. Note small diameter of stalks and depressed growth as compared with the control plants (Fig. 1). Definite leaf and stalk symptoms of nitrogen deficiency appeared on these plants.

Fig. 4. Minus-nitrogen series, at the end of 216 days. Note greatly depressed growth as shown by the narrow leaves, slender stalks and shortened internodes. The root systems were very compact and free from *Pythium* root rot. The individual roots were smaller in diameter than those on the control plants. Nitrogen was again added at the end of 152 days to the solution in which the H 109 plant on the right had been growing. A definite color and growth response was visible within 15 days. The root system on this particular plant began to lose its compactness as a result of *Pythium* root rot.

plant cells. Chemically, protoplasm consists of carbohydrates, water, fats, proteins and a number of the mineral elements such as calcium, potassium, phosphorus, sulphur and iron.

With an abundance of carbohydrates and nitrogenous compounds, vegetative growth is greatly increased. If nitrogen is lacking the carbohydrates continue to accumulate, the leaves begin to develop a chlorotic condition and growth is retarded. If such a condition continues the symptoms become more acute and the plants die.

For normal growth of sugar cane a continuous supply of nitrogen is essential, as briefly explained above. If, however, as the cane plant approaches maturity, the supply of available nitrogen is decreased, the plants become chlorotic, indicating a retardation of vegetative growth and an accumulation of carbohydrates, which conditions are to be desired at this time. Of all the elements essential for plant growth, nitrogen, no doubt, has the greatest effect on cane ripening and juice quality.

Iron

Deficiency Symptoms: In the various deficiency series perhaps the most definite as well as the most easily recognized diagnostic symptoms developed on the plants which were placed in the minus-iron solution.

At the end of 2 or 3 weeks, a pale striping appeared on the young leaves, later becoming very pronounced. The alternating dark green and chlorotic-to-white stripes extended the entire length of the leaves. The normal green color first disappeared from the leaf tissues between the small vascular bundles, leaving green

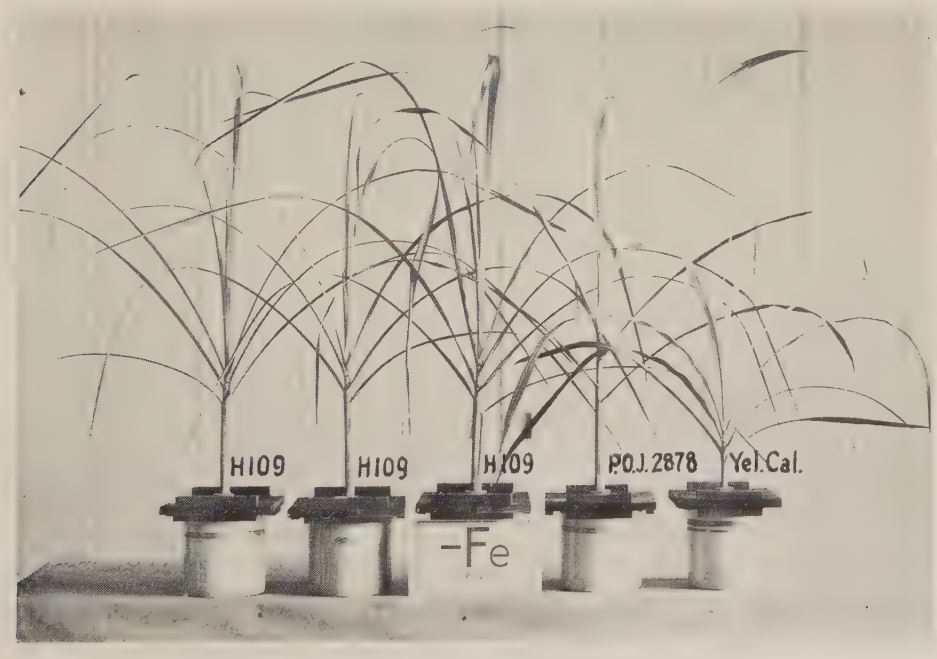


Fig. 5. Minus-iron series, at the end of 80 days. At this time, the growth of the plants was slightly retarded and definite leaf symptoms of iron deficiency were present.

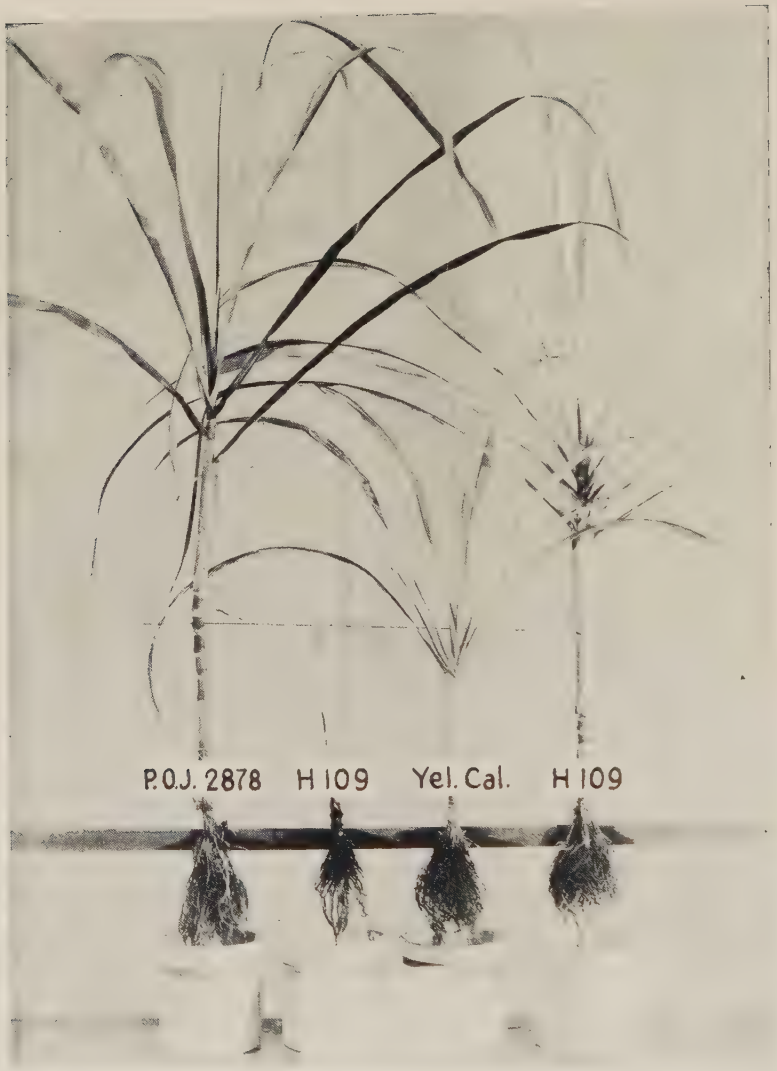


Fig. 6. Minus-iron series, at the end of 216 days. Note the condition of the two center plants which were deprived of iron. The two plants on the ends were sprayed, at the end of 95 days, with a 2 per cent solution of iron sulphate. This treatment corrected the chlorotic condition of the plants for a limited time. Five to six weeks later, these two plants again manifested symptoms of iron deficiency, as shown in the photograph. The roots were severely attacked with *Pythium* root rot and showed the abnormal or "stubby" type of growth as described in the text.

only the chlorophyll-bearing tissues immediately surrounding the large bundles, thus giving the striping effect. Later, this tissue immediately surrounding the large vascular bundles also became chlorotic, rendering the striping less conspicuous and resulting in a more uniformly pale or chlorotic appearance. During this period the older leaves on the plants retained their original dark green color.

Within 6 to 8 weeks, the new leaves were perfectly white except for a trace of light green color in the lower surfaces of the midribs. On leaves unrolling later, no trace of any green color was present (Fig. 5).

There was a strong contrast between the young leaves which were white and the intermediate leaves which were only partially green and still a greater contrast between these young leaves and the old leaves which were of a dark green color. Since only the new growth of the plants in the iron-free solution became chlorotic, this is an indication that iron does not move from the older to the younger parts of the plant.

Two of the plants showing acute iron-deficiency symptoms were sprayed with a 2 per cent solution of iron sulphate, December 27, 1932. A definite greening of the leaves was apparent within 3 or 4 days and at the end of 14 days the plants were of a normal green color. This one treatment corrected the chlorotic condition for 4 to 6 weeks and following this period the new leaves again began to manifest characteristic symptoms of iron deficiency (Fig. 6). The plants which received no additional iron were greatly depressed in growth and soon died (Fig. 6).

The roots of the iron-deficient plants developed an abnormal type of growth, which later proved to be characteristic of plants growing in a minus-iron medium. The growth of the primary roots was greatly retarded; the secondary roots as well as those of the third order were extremely short or "stubby" in growth. A large number of roots were killed by *Pythium* root rot, indicating that an "unbalanced" solution is favorable for the development of this disease.

The symptoms of iron deficiency are shown in Figs. 5 and 6 and in Plate I.

The Function of Iron: Although iron is not a component part of the chlorophyll molecule, it is, however, essential for the formation of chlorophyll in plants. Iron apparently acts as a catalyst in the formation of chlorophyll.

The leaves and stems of plants deprived of iron develop a pale or yellow condition which is known as "chlorosis." If iron is not supplied to chlorotic plants they prematurely die. In water cultures, only small quantities of iron are necessary for normal plant growth.

Phosphorus

Deficiency Symptoms: The cane plants in the minus-phosphorus solution continued to make a normal growth for 6 to 8 weeks. At the end of this time, a slowing up of the growth of the plants was observed (Fig. 7). The newer leaves were narrower in proportion to their length and developed a trace of a greenish-blue color, more noticeable when compared with the dark green color of the leaves on the control plants. Toward the end of the experiment the leaves manifested a slight yellowish-green color. The stalks became slender, a shortening of the internodes was noted and growth in general was greatly retarded (Fig. 8).

The older leaves showed a definite drying and dying at the tips but not as pronounced as the older leaves on the plants in the minus-nitrogen or minus-potassium series. No spotting or striping developed on the leaves.

The roots were decidedly brownish in color and were badly affected with *Pythium* root rot. In recent studies it has been shown that cane roots when grown in water cultures deficient in phosphorus are more susceptible to *Pythium* root rot. Cooke (3) and Carpenter demonstrated that sugar cane is much more susceptible to *Pythium* root rot when grown in soils deficient in phosphorus.

When phosphorus was returned to the minus-phosphorus solution the plants showed a rapid recovery both in color and growth (Fig 8). The diameter of the stalks began to enlarge, the internodes became longer and the leaves became wider and of a normal dark green color.

At no time during the experimental studies were the symptoms of phosphorus deficiency so definite or clear cut as were the deficiency symptoms of the other seven elements. According to the writer's experience, phosphorus-deficiency symptoms as they occur under field conditions are the most difficult ones to recognize. In order to confirm a diagnosis of phosphorus deficiency in the field, it would be advisable to resort to microchemical analyses of plant tissue or to chemical and biological tests of the soil.

Naquin (14), in 1926, described the symptoms of phosphorus deficiency of sugar cane as they appeared under field conditions. In 1932, van den Honert (16), in Java, described phosphorus-deficiency symptoms of sugar cane when grown in culture solutions.

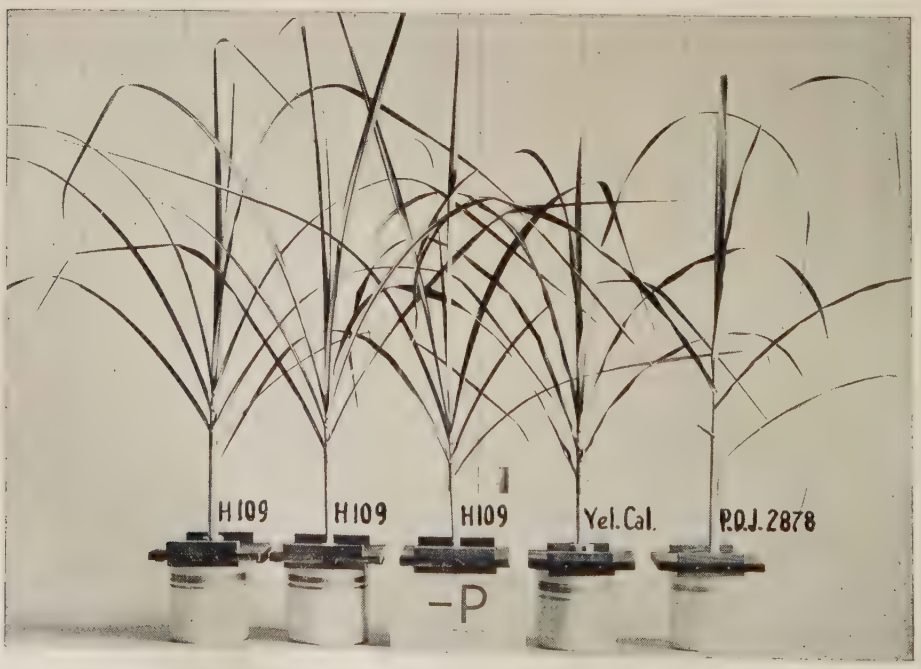
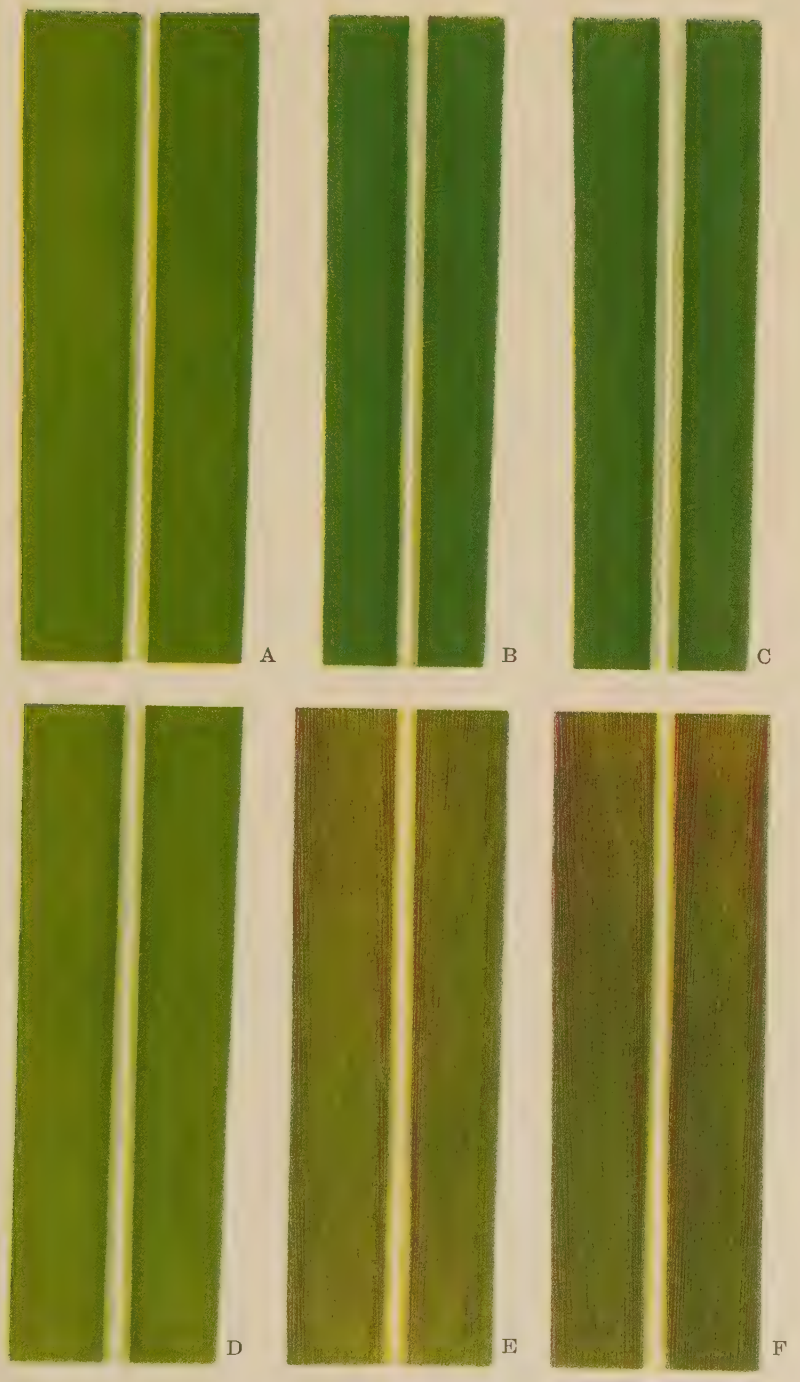


Fig. 7. Minus-phosphorus series, at the end of 80 days. The leaves were of a greenish-blue color in contrast to the normal dark green color of the leaves on the control plants. The growth of the plants was slightly less than that of the control plants (Fig. 1).

PLATE II



A, D—Normal Leaves
B, C—Phosphorus Deficiency
E, F—Sulphur Deficiency

Fig. 8. Minus-phosphorus series, at the end of 216 days. Note the narrow leaves, fan-shaped top, slender stalks, shortened internodes and the tapering of stalks toward the growing point on the three plants on the left. Phosphorus was returned to the H 109 cane plant on the right at the end of 152 days; note the rapid growth response as shown by the elongation and enlargement of the stalk and broad leaf development.

The leaf symptoms of phosphorus deficiency are shown in Plate II and again with the stalk symptoms in Figs. 7 and 8.

The Function of Phosphorus: Phosphorus is an important constituent of proteins but is not required in such large amounts as nitrogen for their formation. Phosphorus occurs in the nucleus, a body, usually spherical, found in living cells, and which is believed to control all the activity that takes place within the cell. Phosphorus is also essential for cell division and for the development of meristematic tissues; it aids in the utilization of certain carbohydrates, particularly starch.

A deficiency of phosphorus interferes with the translocation of carbohydrates within the plant resulting in an accumulation of excess sugars and soluble nitrogen compounds.

Poor bone formation results when cattle are fed on plants deficient in phosphorus. This condition may be corrected by feeding the animals small amounts of bone meal or by applying phosphorus to the soil in which such plants were grown.

Phosphorus is essential during the early life of plants, although the amount required is extremely small when compared with the amounts required of nitrogen, potassium and calcium. It is reported that phosphorus hastens the ripening period of oats and barley if applied shortly before the crops are harvested. It increases tillering of plants and assists in the production of seeds. Large amounts of phosphorus are stored in seeds. It is essential for normal root development and especially so for the development of young roots. In soils low in phosphorus, an abundance of fine or hair-like roots develop, the large roots remaining short and small in diameter.

Sulphur

Deficiency Symptoms: Four to five weeks after sulphur was omitted from the basic solution, the younger leaves of the plants began to lose their normal dark green color. A few weeks later all leaves were of a uniform pale yellowish-green color. The leaf symptoms at this stage were similar to the early leaf symptoms of nitrogen deficiency. As these experiments continued all leaves developed a light lemon-yellow color with a faint purplish tinge on the older leaves. The purplish color became more intense as time went on. Plants deficient in nitrogen did not develop the purple color in the leaves and its presence may be associated with plants deficient in sulphur. The purple color in the leaves is due to the development of anthocyanin, a coloring matter normally found in many species of plants.

The plants in the minus-sulphur series lacked growth and vigor (Figs. 9 and 10), when compared with the control plants. The depressed growth was marked at the end of 6 or 8 weeks. A poor root system developed on the plants and considerable damage resulted from *Pythium* root rot (Fig. 10).

The plants deprived of sulphur and showing definite deficiency symptoms made a quick recovery when sulphur was returned to the nutrient solution (Fig. 10). The plants regained their normal green color and began to make a normal growth. Sulphur-deficiency symptoms on sugar cane are shown in Figs. 9 and 10 and in Plate II.

The Function of Sulphur: Sulphur in combination with carbon, hydrogen, nitrogen and oxygen goes to make proteins which in turn enter largely into the formation of the protoplasm of the plant cells.

A deficiency of sulphur retards the formation of proteins which immediately causes a retardation of plant growth. The leaves gradually lose their dark green color and become chlorotic. This condition indicates an accumulation of carbohydrates in the leaves.

It has been shown that the addition of sulphur to fertilizers has a beneficial effect on plant growth.

Manganese

Deficiency Symptoms: In the deficiency series where manganese was omitted, the plants continued to make what appeared to be a normal growth for 2 months (Fig. 11). At the end of this time the first leaf symptoms were observed. On the young leaves, a leaf striping somewhat similar to the early symptoms of iron deficiency appeared. The striping developed more frequently toward the middle and tips of the leaves and seldom continued the full length of the leaves. This characteristic has proved valuable for differentiating the early symptoms of manganese deficiency from those of iron deficiency.

The leaves at first showed alternating dark green and light green stripes, the former being slightly the wider. At the end of 3 months, the light green stripes were almost entirely chlorotic or white and the effect was very marked. As the experiment continued, the dark green stripes became slightly chlorotic, thus making the striping less conspicuous. Small necrotic regions soon appeared in the

Fig. 9. Minus-sulphur series, at the end of 80 days. The growth of the plants was retarded and definite leaf symptoms of sulphur deficiency were present on the leaves.

Fig. 10. Minus-sulphur series, at the end of 216 days. Note greatly depressed growth and poor root development especially on the three plants on the left. The leaves on these plants were of a pale yellowish-green color with traces of a purplish tinge on the older leaves. When sulphur was returned to the solution, a normal growth resulted, as shown by the H 109 cane plant on the right.

PLATE III

A—Normal Leaf
B, C—Manganese Deficiency
D, E, F, G—Potassium Deficiency

white stripes; later, these regions coalesced, making continuous stripes of dead, dry tissue, which frequently split or cracked longitudinally. At one time, this nutritional condition was called leaf splitting disease and was attributed to the fungus, *Mycosphaerella striatiformans*. This leaf trouble, the cause of which is a deficiency of manganese, is commonly known as Pahala blight.

Shortly after the leaf symptoms developed, the plants failed to make further growth. The leaf and stalk tissues became soft and "rubbery" in texture. Due to this weakened condition, the leaves began to droop and the youngest leaves began to die. The plants, in an effort to continue their growth, developed side shoots but these were also extremely weak. The root systems were in a weakened condition, *Pythium* root rot was present in abundance (Fig. 12), and the plants soon died.

When manganese was added to the nutrient solution containing the dying plants, normal color developed and growth was resumed, while the leaves which developed were free from any leaf striping (Fig. 12). The addition of manganese to the culture solution which was at the rate of .25 p. p. m. or approximately three-quarters of a pound per acre, clearly demonstrates the necessity of having certain elements present even though the amount sometimes appears to be almost negligible.

Symptoms of Pahala blight occurring on sugar cane in the fields have been described by Cobb (2), Lyon (10), McGeorge (11), and Lee and McHargue (9). The symptoms of Pahala blight, or manganese deficiency, appearing on sugar cane grown in culture solutions have been described by Davis (4) and Martin (12).

Fig. 11. Minus-manganese series, at the end of 80 days. The growth of the cane plants up to this time was about equal to that of the control plants (Fig. 1), although definite leaf symptoms of manganese deficiency were present.

Fig. 12. Minus-manganese series, at the end of 216 days. The three plants on the left failed to make further growth, the leaf and stalk tissues became soft and "rubbery", the leaves began to droop, and the leaf spindles began to die. The leaf striping or symptoms of manganese deficiency were very acute. The roots were poorly developed and greatly weakened by *Pythium* root rot. When manganese was again added to the solution the deficiency symptoms quickly disappeared and the plant made a normal growth, as shown by the H 109 cane plant on the right.

Leaf and stalk symptoms of manganese deficiency are shown in Figs. 11 and 12 and in Plate III.

The Function of Manganese: It has been demonstrated that extremely small quantities of manganese are essential for the growth of certain plants. However, the role that manganese plays in plant metabolism is not clearly understood.

Manganese is said to aid in certain oxidation processes that take place in the plant. It seems to be of special importance to the development of the immature tissues at or near the growing point.

The sugar cane plants in the minus-manganese series were found to have a low activity in oxidase by Dr. C. E. Hartt, who is conducting special studies on the activities of enzymes in the cane plant at this Experiment Station.

Miller (13) states:

> The function performed by Mn in the metabolism of the plant rests almost entirely on theoretical grounds. Bertrand (1897, 1905, and 1912) considered that the addition of small amounts of soluble Mn increases the oxygen-carrying power of the oxidases. This enzyme is universally present in plants and fulfills a definite function in their metabolism . . . . . McHargue (1922) thinks that manganese is concerned in nitrogen assimilation and the synthesis of proteins and that it plays the role of a necessary catalyst in plant metabolism and also functions with iron in the synthesis of chlorophyll.

Potassium

Deficiency Symptoms: The first visible deficiency symptoms exhibited by the plants in the minus-potassium solution was the retardation of growth. At the end of 4 to 6 weeks, the growth of the plants was greatly retarded; the stalks tapered rapidly toward the growing point and the tops assumed a fan-like appearance (Figs. 13 and 14).

The older leaves began to die back from the tips and margins, resulting in a definite firing of the leaf edges. The older leaves also gradually changed from a dark green to a pale yellowish color and on these leaves numerous minute chlorotic spots appeared. These spots later became brown with necrotic centers. The leaf spotting was much more pronounced on the older leaves than on the younger leaves. In advanced cases the leaf spotting was very common, the part affected being the parenchyma, or the tissue that lies between the vascular bundles. The young leaves of plants deficient in potassium developed a darker green than the control plants.

The above symptoms are similar to those described by Naquin (14) in 1926; his description was of plants which were grown under field conditions.

A very definite reddish discoloration appeared on the upper surfaces of the midribs of the older leaves and was most pronounced toward the bases of the leaves. The presence of this midrib discoloration is one of the most definite symptoms for recognizing potassium deficiency in sugar cane plants. The discoloration is due to the development of a red color in the cell wall which is limited almost entirely to the cells near the upper surface of the midrib.

Upon the addition of potassium, the plants in the minus-potassium series rapidly assumed a normal growth (Fig 14). The leaf symptoms quickly disappeared and the color of the plants became normal.

An abnormal root development resulted in this series. The roots were badly attacked with *Pythium* root rot.

Potassium-deficiency symptoms developing on sugar cane in culture solutions have been studied and described by Hartt (5) and van den Honert (16).

Symptoms of potassium deficiency are shown in Figs. 13 and 14 and in Plate III.

The Function of Potassium: Potassium is required by plants in rather large amounts. Almost all of the potassium contained in plant tissues is readily soluble in water and possibly occurs in plant cells in inorganic form. Potassium migrates from the older parts of the plants toward the meristematic, or growing, tissues; this is evidenced by cane plants deficient in this element. The older leaves gradually manifest potassium-deficiency symptoms and if a shortage of potassium continues, the symptoms become extremely pronounced on the older leaves and begin to develop on the younger leaves. The youngest leaves are the last to manifest the symptoms which may be explained by the movement of potassium within the plant from the older to the younger leaves.

It is thought that potassium aids in carbon assimilation, translocation of sugars, and in starch formation. Potassium is essential for the general processes of cell division, although its specific role in this connection is not clear. Sweet potatoes and sugar beets deficient in potassium become elongated and small in diameter.

There is considerable evidence that a deficiency of potassium interferes with the formation of proteins, the formation and digestion of carbohydrates, and probably with the translocation of these materials.

Fig. 13. Minus-potassium series, at the end of 80 days. The growth of the plants was depressed and definite leaf symptoms of potassium deficiency were present.

Fig. 14. Minus-potassium series, at the end of 216 days. Growth was greatly retarded, the stalks were small in diameter and definite leaf symptoms of potassium deficiency appeared on the plants At the end of 152 days, potassium was again added to the solution in which the H 109 plant on the right had been growing; a normal growth resulted and the deficiency leaf symptoms disappeared.

Under some conditions, potassium salts apparently facilitate the entry of water into the plant. An adequate supply of potassium is essential for normal root development. An inadequate supply results in the development of primary roots that are abnormally fine and which develop few secondary roots.

Dr. Hartt, who has contributed extensively to a better understanding of the physiological role of potassium in the sugar cane plant, summarizes her studies to date as follows:

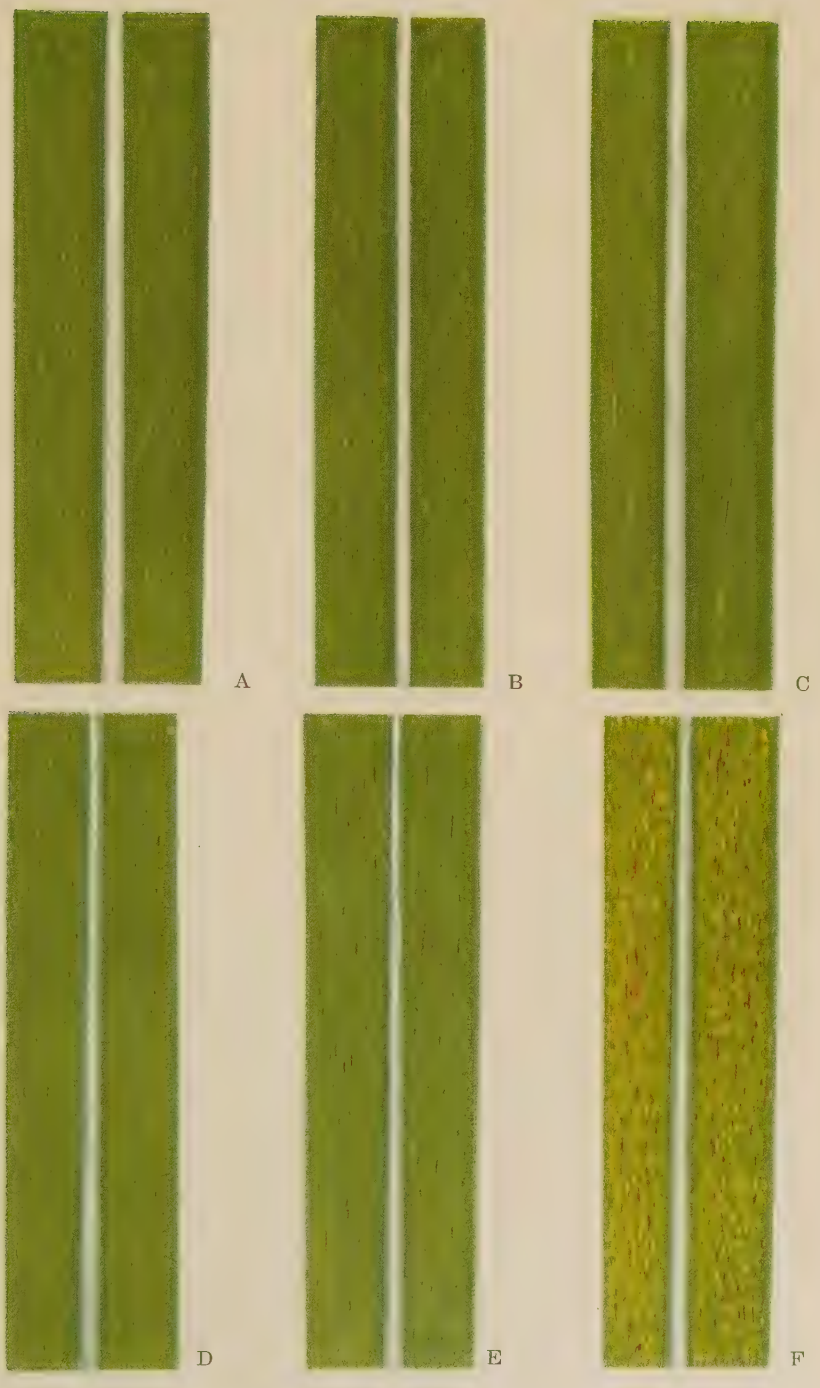
> The symptoms of potassium deficiency in sugar cane were found to be decreased growth (5, 7), "dieback" and discoloration of the leaves. The development of red midribs in plants deficient in potassium was associated with an excess of sulphates or possibly chlorides (7).
>
> In 1929 (5), a report was made of the results of quantitative determinations of the activity of diastase, invertase, peptase, ereptase and catalase. The effect of potassium upon enzyme activity was found to vary with the kind of enzyme, the species, age and organ of the plant studied. The potassium-deficient plants had greatest diastase activity in all parts except the roots, in which activity was equal in all the plants. The invertase activity in the blades was greater in the controls than in the potassium-deficient plants. Peptase and catalase activities were greatest in the plants supplied with potassium. Ereptase activity was the same in all the plants. Differences were also found in moisture, sugars, lignification and cutinization. Greater lignification and higher percentages of sugars were found associated with a weak activity of peptase in the plants deficient in potassium, suggesting the conclusion that an upset in the synthesis of proteins may lead to the accumulation of carbohydrates, a conclusion reached by Nightingale et al. (15) in 1930, who found the accumulations of carbohydrates to be an early response in potassium deficiency, disappearing later.
>
> In a later study, the effects of potassium upon the growth of sugar cane and upon the absorption and migrations of ash constituents (7), as well as upon the amounts of protein and amino forms of nitrogen, sugars and enzyme activity are reported (8). Higher percentages of reducing sugars and lower percentages of sucrose were found associated with weaker activity of invertase in the blades of the plants deficient in potassium (8). The plants deficient in potassium developed the following characteristics: low percentages of moisture; high total ash content when young, followed later by low ash percentage, high percentages of calcium, magnesium, phosphorus and iron at certain ages, derangements in the synthesis and translocation of proteins and sugars; phloem necrosis, accumulation of iron at the nodes; weak activity of invertase and strong amylase activity. Migration of potassium from the lower dying leaves to the living tops occurred in all the series and was not associated with a deficiency in potassium.

Magnesium

Deficiency Symptoms: A reduction in growth of the cane plants in the minus-magnesium series was noted at the end of 4 weeks. The stalks became slender and the older leaves manifested a chlorotic condition (Fig. 15). The young leaves lost some of their dark green color but not to the extent of the more mature ones.

Within 4 to 6 weeks, minute chlorotic spots began to appear on the older leaves. Later these spots turned to a dark brown color and were uniformly distributed over the surface of the leaves. The minute spots or lesions were extremely common and frequently coalesced, thus giving a "rusty" appearance to the leaves. The spotting was most pronounced on the older leaves and decreased in severity on the younger leaves.

PLATE IV



A, B, C—Magnesium Deficiency
D, E, F—Calcium Deficiency

The growth of the plants at the end of 216 days (Fig. 16) was greatly reduced when compared with the growth of the control plants. In this series, P. O. J. 2878 produced the greatest amount of growth while Yellow Caledonia produced the least. It is interesting to note that P. O. J. 2878 made more growth than the other two varieties in practically every deficiency series.

When plants deficient in magnesium were transferred to a solution containing magnesium, the new growth produced was normal and the chlorotic leaves regained their normal green color (Fig. 16). No further leaf spotting developed.

Symptoms of magnesium deficiency are shown in Figs. 15 and 16 and in Plate IV.

The Function of Magnesium: Magnesium is one of the constituents of the chlorophyll molecule and a deficiency of this element in a plant would naturally reduce or prevent the formation of chlorophyll. A shortage of magnesium would, therefore, result in a chlorotic condition of the leaves or green parts of the plant.

Magnesium, according to some investigators, aids in the translocation of phosphorus, particularly from the older to the more rapidly growing parts of the plant.

It has also been pointed out that magnesium is essential for the formation and utilization of oils in plants. Seeds having high oil content contain much more magnesium than those having a high starch content.

An excess of magnesium may prove toxic to plant growth and is sometimes corrected by the addition of calcium to the soil, usually in the form of agricultural lime. Considerable experimental work has been carried out in relation to the calcium-magnesium ratio in plants as well as in the soil.

Fig. 15. Minus-magnesium series, at the end of 80 days. The growth of the plants was slightly less than the growth of the control plants (Fig. 1). Very definite leaf symptoms of magnesium deficiency appeared on these plants.

Fig. 16. Minus-magnesium series, at the end of 216 days. Cane growth was greatly retarded in contrast with the control plants (Fig. 2). The leaf spotting or leaf symptoms were very pronounced on the older leaves. Considerable root injury resulted from *Pythium* root rot. Upon the return of magnesium to the H 109 cane plant on the right, normal growth resulted; no further leaf symptoms appeared.

CALCIUM

Deficiency Symptoms: In the various deficiency series, the greatest injury to the plants occurred in the minus-calcium solution.

Within 3 to 4 weeks, a slight chlorotic condition of the leaves as well as a marked retardation of growth resulted (Fig. 17). Minute spots, giving a peppered appearance, also began to develop on the older leaves. These spots were extremely numerous and later became dark reddish-brown in color with dead centers. The necrotic areas soon coalesced and almost the entire leaf was involved. In such cases, the leaves quickly died. The injury from the spotting increased with the age of the leaves; however, severe injury occurred on comparatively young leaves. The spots resembled those in the minus-potassium series and the minus-magnesium series.

The innermost or youngest leaves became extremely weak and failed to make further growth. This condition was followed by the death of the spindle, the growing point of each plant, and, in a few cases the entire plant (Fig. 18).

The effect on the root growth was very marked. Root development was greatly retarded in 2 to 3 weeks after calcium had been omitted from the nutrient solution. The roots became soft and flaccid as a result of *Pythium* root rot. At the end of 8 to 10 weeks, the rot was so severe that practically every root had died. The greatest damage from *Pythium* root rot occurred in this series.

When the rapidly dying plants were placed in a plus-calcium solution, an immediate growth response resulted (Fig. 18). Since the terminal bud had died on

Fig. 17. Minus-calcium series, at the end of 80 days. The growth of these plants was greatly depressed when compared with that of the control plants (Fig. 1). The leaf symptoms of calcium deficiency were very pronounced. Severe root injury from *Pythium* root rot occurred on these plants. The plants in general were in a very weakened condition.

Fig. 18. Minus-calcium series, at the end of 216 days. The three plants on the left have died. These plants made little or no growth after calcium was removed from the solution. The roots were severely injured by *Pythium* root rot. Calcium was returned to the H 109 cane plant on the right at the end of 152 days. The growing point had already died but a rapid growth developed from the lateral buds. The new growth was normal in every respect.

each plant in the minus-calcium solution, the lateral or side buds began to develop shoots of a normal color and growth.

Leaf and stalk symptoms of calcium deficiency are shown in Figs. 17 and 18 and in Plate IV.

The Function of Calcium: Calcium is regarded by some as the key element in relation to the absorption of the other elements. A nutrient solution minus calcium is no better for plant growth than distilled water.

With a good supply of calcium, the cell wall constituents are rendered more firm, due to the formation of calcium pectate, which is the cementing substance that holds the cells together. Between the cells is found the middle lamella, which is composed of calcium pectate.

It is thought that certain calcium salts form a precipitate which constitutes a semi-permeable membrane, and that this membrane offers protection to the protoplasm by preventing the contact of toxic elements with the protoplasm. Calcium is considered an antitoxic agent in that it prevents injury to the protoplasm of the cell that certain ions might produce. For instance, magnesium in high concentrations is toxic to plant growth but with the addition of calcium, the same concentration of magnesium is rendered non-toxic. Gypsum, or calcium sulphate, is frequently applied to alkali soils to counteract the harmful effect from excesses of magnesium or sodium.

With a calcium deficiency, an over-accumulation of carbohydrates occurs and a disintegration of phloem takes place and, in the case of the latter, the translocation of foods is delayed which often results in an accumulation of starch in the leaves.

Calcium is essential for normal root development. With a deficiency of this element the roots are greatly weakened and are subject to attack by parasitic organisms. This was specially true in relation to the root development of sugar cane plants which were grown in a minus-calcium solution. The roots were severely affected by *Pythium* root rot.

IV. Discussion

The quantity and availability of the essential elements for plant growth occurring in the soil or culture solutions govern, to a large extent, the amount of any one element found in the plant. It is possible to change the chemical composition of the plant by altering the medium in which it is grown.

A chemical analysis of plants grown in a nutrient solution, from which an element has been omitted, shows that the proportionate amounts of the various elements present in these plants differ from the amounts of the same elements in plants grown in a complete nutrient solution. This was found to be true in more recent studies in which chemical analyses were made of sugar cane plants grown in solutions deficient in each of the eight elements referred to in this paper. The effects on growth, when any one element was omitted, may have been because, (1) the element was essential for certain metabolic processes within the plant, or (2) the rate of absorption of the various elements was affected by the antagonism which resulted among the elements in the "unbalanced" solution. In either case

the effects on the plants were characteristic for each element omitted, thus making it possible to distinguish *deficiency symptoms* of one element from another.

It required much more time for the deficiency symptoms to develop on the plants after they were placed in the incomplete solutions than it did for the plants to manifest a recovery when the element was again added to the medium. The plants, no doubt, absorbed the elements in excess of their requirements before they were transferred to the deficiency series and manifested an abnormal growth only after the reserve of the element was exhausted within the plant in each deficiency series.

Of the three cane varieties, Yellow Caledonia was, without exception, the first to manifest the deficiency symptoms, while H 109 and P. O. J. 2878 were next in order. In each deficiency series, the growth of P. O. J. 2878 was much superior to the other two varieties. Possibly, the culture solution was more favorable for the growth of P. O. J. 2878, or that smaller quantities of the elements were required for its development, or that P. O. J. 2878 built up a greater reserve of all elements than the other varieties at the beginning of the experiment.

V. Summary

1. A nutrient solution, containing the elements essential for plant growth, was found to be favorable for normal growth of the sugar cane plant. Methods for growing sugar cane plants in water cultures are described.

2. When nitrogen, iron, phosphorus, sulphur, manganese, potassium, magnesium or calcium was omitted from the complete nutrient solution, an abnormal growth of sugar cane plants resulted.

3. A reduction in cane growth occurred in each deficiency series, i. e., when any one of the eight elements was omitted from the solution.

4. Definite leaf, stalk or root symptoms developed on plants in each deficiency series. Deficiency symptoms of each element are described and illustrated.

5. The deficiency symptoms which proved to be typical for each element may serve to distinguish similar deficiency symptoms should they appear on sugar cane when grown under field conditions.

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Notes on New Varieties

28-1234 (P.O.J. 2364 x 26 C 270).

A three-replication test comparing 28-1234 with H 109 was harvested recently at Waianae Company by F. C. Denison in cooperation with the plantation. In view of the widespread interest in this seedling it may be in order to report the results in detail.

The experiment was planted on March 5, 1932, and harvested on April 7, 1934, at 25 months of age. It was situated in Field 28, a low-lying, level field, with a fertile loamy soil. The plots were of watercourse size, one-sixth to one-tenth acre each, with check plots of H 109 adjoining. The yield data are given below:

	No. of Plots	TC/A	Q. R.	Yield % Cane	TS/A	TS/A Gain
28-1234	3	129.9	9.08	11.01	14.3	3.0
H 109	5	98.5	8.85	11.50	11.3	

It was obvious as the cane lay on the ground at harvest that the 28-1234 had made a heavier tonnage than H 109. However, considerably more dead cane could be seen in the 28-1234 than in the H 109 plots. It appeared that 28-1234 had passed its prime and that it would have performed to still better advantage had the test been harvested a few months earlier.*

It is a matter of considerable interest that 28-1234 should have defeated H 109 under conditions particularly suited to the latter variety. We believe, however, that this seedling will prove most useful under less fertile conditions where H 109 fails to produce satisfactory tonnages.

* It should be mentioned that 28-2014, a sister of 28-1234, also did remarkably well in this test, outyielding even 28-1234 by a small margin.

Another bit of evidence in support of 28-1234 has recently come from the Hamakua Variety Station, the conditions of which are quite the opposite of those which prevailed in the Waianae experiment reported above. The Hamakua Variety Station is situated at an elevation of 1,100 feet, and the seedlings in this Field Trial 2 planting have had to contend with two periods of extreme drought. Under these adverse conditions 28-1234 stood at the head of the list of some 40 seedlings, outyielding P.O.J. 36 by over four tons of sugar per acre. The juices of 28-1234 were slightly better than those of the P.O.J. 36 check plots.

The versatility of 28-1234 is such that it may be recommended for trial under all conditions except in localities where eye-spot disease is severe. While not as susceptible as H 109, it has nevertheless been badly affected in areas particularly favorable to the development of the disease.

31-1389 (P.O.J. 2878 x 26 C 270).

This seedling is closely related to 28-1234, as shown by the above parentage.

Reports from tests of 31-1389 under makai conditions point to it as the strongest competitor of H 109 and P.O.J. 2878 now in the field. It is highly resistant to eye-spot disease and can be used to replace H 109 under conditions of severe eye-spot with full assurance of improved yields. Preliminary juice tests have been equal to or better than those of the check varieties.

At Waipio Substation this seedling has been consistently ahead of H 109 in all plantings. At Kailua Substation it is superior to P.O.J. 2878. On the plantations it is doing particularly well in preliminary tests at Lihue, Grove Farm, Kekaha, Honolulu Plantation, Ewa, Waialua, Waimanalo, and Maui Agricultural Company.

31-1389 is characterized in all districts by a freckling on the older leaves. This freckling apparently has little effect on the growth of the cane.

Whether 31-1389 will succeed under mauka conditions is questionable. In weedy situations it is likely to prove too open. Under good makai conditions, however, it is unquestionably one of the best of the long list of seedlings now under trial on the plantations. It deserves rapid spreading and thorough testing in all fields where H 109 and P.O.J. 2878 are now being grown.

A. J. M.

The Sugar Cane Plant

A STUDY OF MILLABLE CANE AND SUCROSE FORMATION*

By U. K. Das

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* A progress report of this work has already appeared in *The Hawaiian Planters' Record*, Vol. XXXVI, pp. 399-422, 1932. Some data and discussion contained in that report are here included for the sake of completeness.

I. Introduction

In spite of the excellent agricultural control of our plantations in Hawaii, the cane yield and the juice quality vary tremendously from year to year on the same plantation. Several years ago the writer undertook a series of weather studies in an effort to determine how much of these annual fluctuations could be due to variations in the weather conditions, particularly temperature and rainfall. Mild though these weather variations be in Hawaii compared with many other cane-growing regions, they were, nevertheless, found to exert great influence on our yields, especially cane yields. However, after due allowance was made for changes in cultural policy and the fluctuations in weather conditions, we were still left with unaccountable variations which were particularly large in the case of juice quality. It seemed desirable, therefore, that preparatory to a full understanding of the yield and quality of a cane crop all the factors bearing upon the problem be studied in a systematic manner. The present investigation forms the first part of that broad project.

As we all know, a cane crop is propagated vegetatively by planting seedpieces in the ground. Under favorable conditions of heat and moisture a dormant eye on these seedpieces germinates giving rise to a stalk of cane. In a similar manner this first stalk may later give rise to one or more daughter stalks and these latter may, in course of time, produce granddaughter stalks. At the time of harvest, which in Hawaii is usually 18 to 20 months after planting, the crop may consist of stalks of various ages and consequently in various stages of vigor and maturity. As a first step to a better understanding of our crops, we must therefore know just what a cane crop is, and determine how and to what extent these component parts of a crop affect its average yield and quality.

II. Plan of the Experiment

A uniform area of land at the Experiment Station in Honolulu was divided into eight sections, each section containing 10 lines, each line 35 feet long and 5 feet wide (Fig. 1). Four sections were planted in March and four in September, so that the variations induced by the season of planting could also be studied.

Variety of cane: H 109, which produces roughly 60 per cent of the total yield of Hawaiian sugar plantations.

Seed: Both body and top seed—three-eye pieces.

Fertilization: Uniform in both seasons of planting. Fertilizers were distributed as follows:

At the time of planting 50 lbs. N per acre from ammonium sulphate.
200 lbs. P_2O_5 per acre from superphosphate.
200 lbs. K_2O per acre from potassium sulphate.

At 3 months 50 lbs. N per acre from ammonium sulphate.

At 6 months 75 lbs. N per acre from ammonium sulphate.

At 12 months 50 lbs. N per acre from ammonium sulphate.

Total application: 225 lbs. N per acre.
200 lbs. P_2O_5 per acre.
200 lbs. K_2O per acre.

These amounts are considered to be optimum for average H 109 conditions.

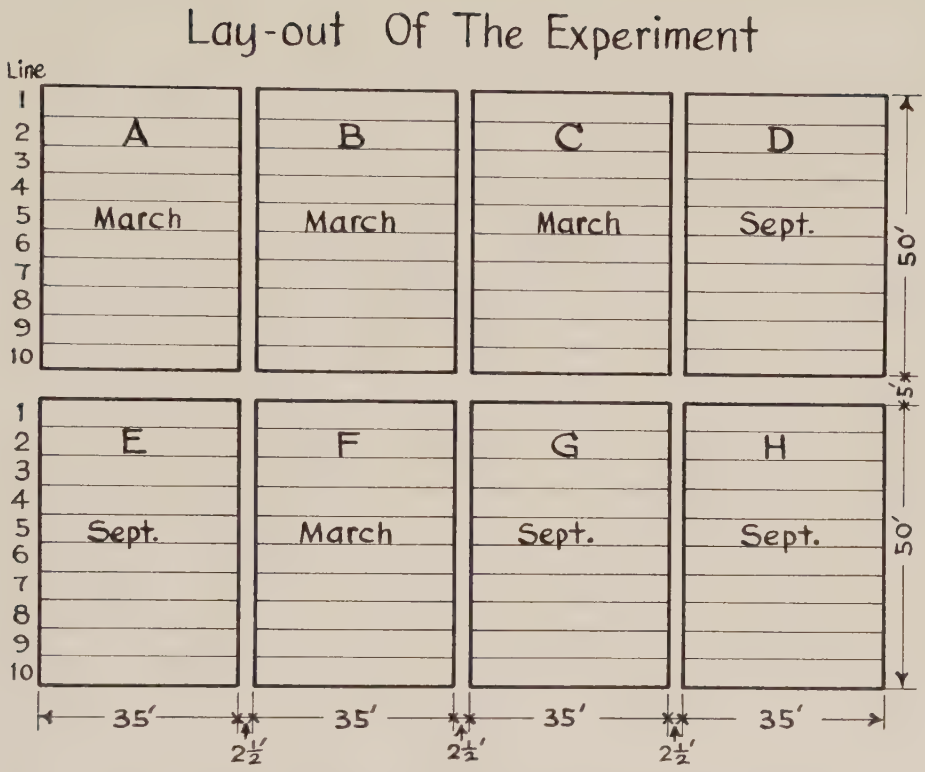
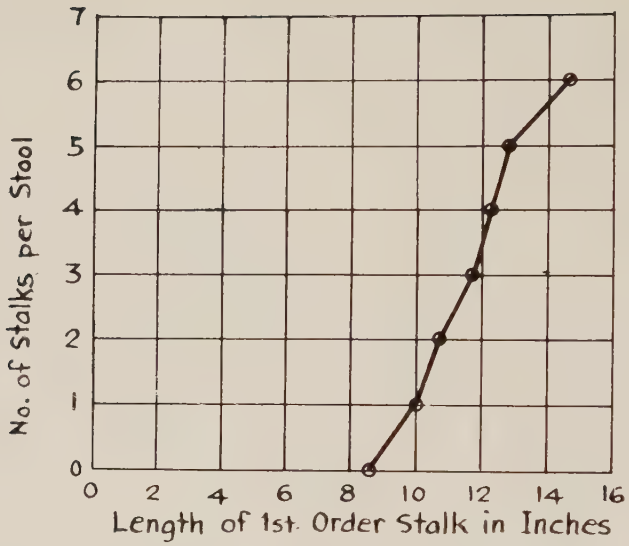


Fig. 1.

Irrigation: Two inches per application, two applications a week. Allowance was made for heavy showers only. Sixteen inches of water applied thus every month is considered to be ample in the irrigated districts of this Territory. The plots were irrigated right to the day of harvest—no attempt being made to influence juice quality by withholding water for a certain length of time before harvest.

On March 17, and September 17, 35 uniform three-eye seedpiecees were planted in each line containing 3 x 35, or 105 potential stalks. After the germination was completed, which took about four weeks, the rows were thinned keeping only 35 more or less uniform stalks to the line. This thinning was undertaken in order to insure a uniform stand of cane in each line. These original shoots which sprung from the seedpieces are herein called mother stalks, primary stalks, or stalks of the first order. Each of these first-order stalks then formed the nucleus of a stool of cane, which consisted of the mother stalk and all the other stalks that arose directly or indirectly from the mother stalks. We then had 35 stools or one stool to a running foot of row in each line.

The first-order stalks were tagged, each tag bearing a number denoting its serial position in the row. Thereafter, at intervals of about two months, the field



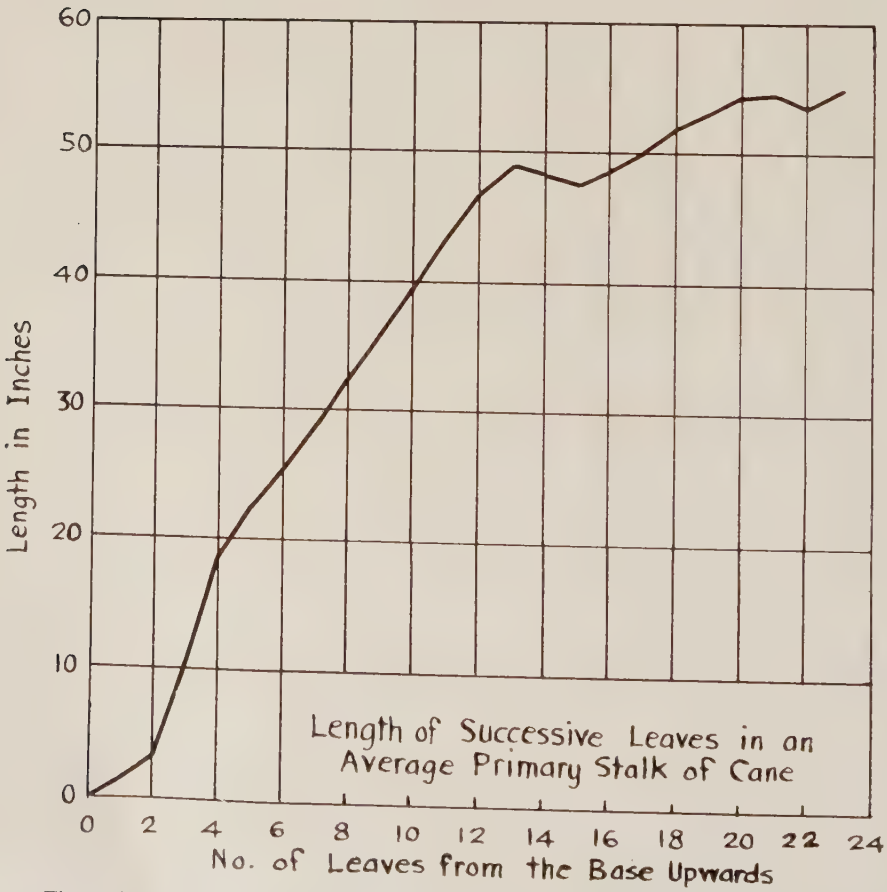


Fig. 2 (above). Showing that at 2½ months of age, the number of shoots per stool is closely related to the size of the primary or first-order stalk. Vigorous primary stalks would therefore insure a good and early stand of cane.

Fig. 2-A (below). As the shoot germinates, the first leaf is very small. Thereafter each successive leaf increases rapidly in length reaching approximately normal length for H 109 around the twenty-fifth leaf. The curve shows three well defined slopes between the first and the twenty-third leaf, the slope flattens out in adult cane, the length remaining more or less constant thereafter as long as the plant is in good vegetative condition.

was carefully gone through and all the shoots that had germinated since our previous tagging were marked with a different kind of tag and these newcomers were successively called the second, third, or higher-order stalks. Order in this paper, therefore, *refers to time of germination* only and not to any morphological relationship of one shoot to another.

III. Suckering—Variations and Seasonal Influences

Individual differences or variations appear to be the most characteristic feature of a growing crop of cane. Starting with selected and uniform seeds and thinning the stand of cane for uniformity, we still find at the age of about 10 weeks that there are great variations in suckering from stool to stool. The number of second-order stalks per stool varies from six to none at all. The first-order stalks show differences among themselves in the matter of size of stalks, number of leaves, and size of leaves.

The number of second-order stalks at this age appears to be correlated to the size of the first-order stalk. The larger the latter, the more numerous the former, as Table I and Fig. 2 will show. This would mean that the rapidity of growth of the first order has an important bearing on the early establishment of a close, thick stand of cane.

Next to this variation in the number of stalks from stool to stool we have the variation in the total number of stalks per line at different ages. Beginning at the age of four weeks we counted the total number of stalks per line at intervals of time. Every care was taken to disturb the cane as little as possible and otherwise keep the conditions approximating field conditions. The results are shown in Table II and Fig. 3.

March planting: Lines 1, 2, and 3 in Sections A, B, C, and F were selected for shoot counts. The total number of lines were 12 representing 420 running feet of row or 420 stools of cane.

We see that at about one month of age this plant field of H 109 has only 35 stalks per line, i.e., there are no suckers.* From then on the number of shoots per line increases to a maximum at about 4½ months of age. This maximum occurs in the early part of August and is followed by a sharp decline continuing through the fall and winter months. There is a little increase in number in the spring of the second year but later harvesting data have shown that this slight increase was offset by the death of older stalks.

Fig. 3 shows only the net results but fails to bring out that in a growing field of cane suckering is a continuous process. Some new suckers are always coming up and others dying, so the population is never exactly the same, though the total number may remain constant.

In the outside line the progress of suckering is quite different from that in the two inside lines. The outside line rises to a greater maximum and the total number does not fall to the level of the two inside lines. Later on we will show that this is due to more space and greater exposure to light obtained by the outside rows.

* In all the following discussion it must be kept in mind that in this experiment the original stand was thinned to contain only one primary stalk per running foot. The picture might have been different with closer or wider planting.

Number of Stalks per Line on Different Dates - Sec. A, B, C & F

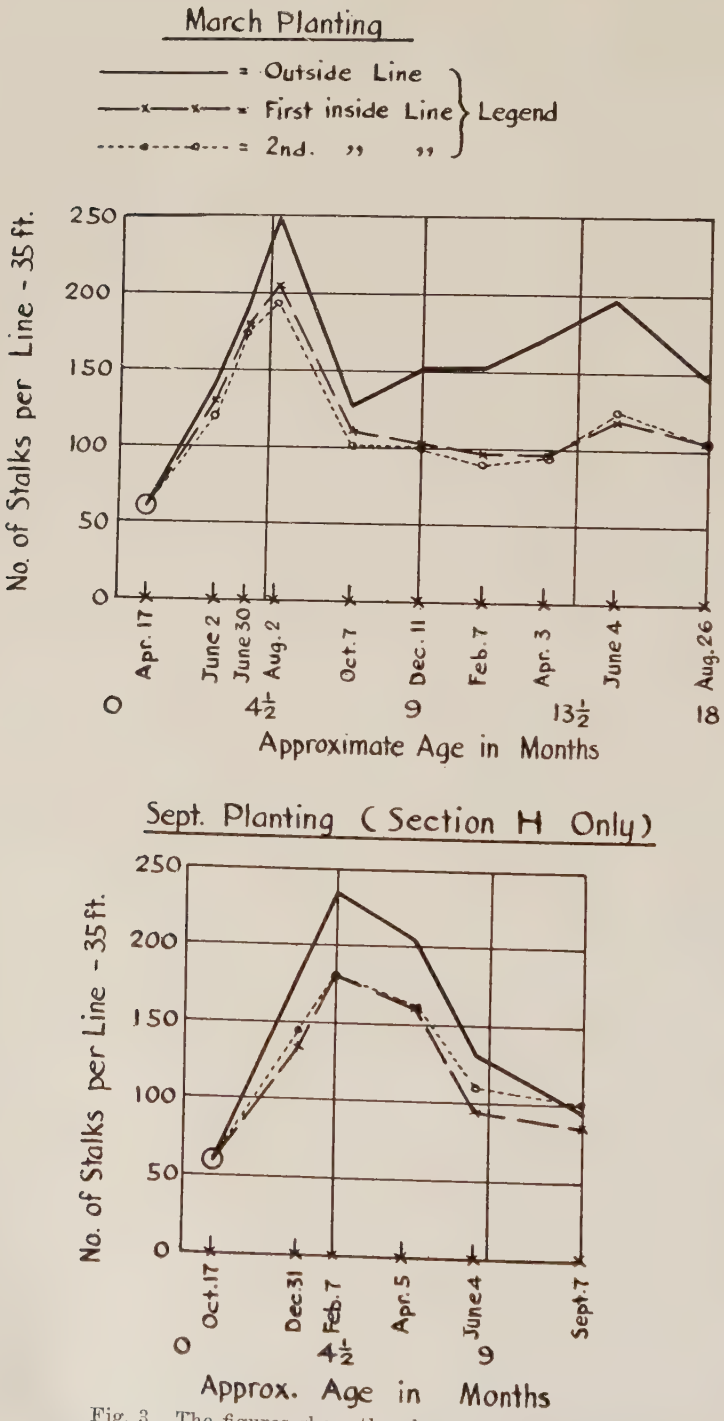


Fig. 3. The figures show the changes in the population of the field at various ages. One month after planting (April 17 and October 17) there are only 35 primary or first-order stalks in each line. The number of stalks then rises to a maximum of about 250 at 4½ months of age. This maximum is immediately followed by heavy mortality, the number coming down to about 95 per line and remaining more or less constant thereafter. The mortality is due to self shading from plant competition and not to the season of the year.

September planting: Sections D, E, G, and H were planted in September. At this time, Sections A, B, C, and F had canes already six months old. The end stools in Sections D, E, and G did not get the full amount of sunlight. The shoot count data in these sections are of great interest in showing the effects of shading. However, for the purpose of Fig. 3 only the data from three rows of Section H are summarized, for this is the only section that was not handicapped by the border effect of big cane. The total number of stools here is only 105, but the progress of suckering is identically the same as in the March planting. Starting with 35 stalks per line at one month the number rises to a maximum at about 4½ months and then declines sharply. Contrary to observations reported by others, this decline starts in the beginning of spring and continues through the spring and summer months. Season of planting or season of the year has, therefore, little to do with the general sucker mortality which takes place in every crop. It will also be observed that in the outside row of Section H, the number of shoots gradually approaches the total of the two inside lines. A study of the layout will show that line 1 in Section H is not an outside line in the sense that line 1 in Sections A, B, or C is. There is only a 2½-foot path separating Section D from Section H. When the cane in Section D had grown large, line 1 in Section H ceased to have the same space and light as a true outside line.

IV. Factors in Suckering

All evidence points to the fact that suckering is predominantly influenced by light and exposure, which factors are materially altered inside a cane field by plant competition.

In both plantings the outside lines have a larger number of suckers than the inside lines. In March plantings the total number of shoots in the outside lines rises to a maximum of 250 per line or about 7 per lineal foot. In the inside line this is about 5½ per foot. At the time of maximum stooling the 24 end stools in the 12 lines averaged 9½ shoots per stool but the inside stools averaged only 6 per stool.

The sudden rise in the number of shoots obtained in December for the outside lines of March-planted cane is explained by the fact that an adjoining field of cane was cut in October. The outside lines, therefore, received an increased amount of light and space which were at once reflected by an increased number of suckers in the outside lines.

The inside lines do not show this effect as will be seen from Table III. Section F, which did not have the benefit of this exposure, also does not show any material increase in the number of shoots.

It has been observed previously that in September-planted cane, the end stools in some of the sections did not receive full sunlight. Some were deprived of early morning light and some of afternoon light. These stools show very irregular and delayed suckering compared with the other stools that received full sunlight. Thus in Section E, in the end stools which did not receive morning light until about ten o'clock, there were no suckers of the second or higher order until after the fourth month. But the point of interest is this: that the same stools caught up with the others in the number of suckers later on. In other words suckering was not

stopped but only delayed. This naturally raises a question as to the exact nature of suckering. Do the plants need a certain minimum or a balance of some essential factors before they will produce suckers? If this condition is satisfied in two months, suckers will start in two months. If it should take six months for the plants to obtain the minimum or the required balance, suckering may well be delayed for six months. The factors may be total quantity of light, heat or some physiological condition within the plant.

Plant competition: In a field of cane, plant competition has probably a more direct bearing on sucker production than anything else. We use the word "direct" purposely, for the factor of competition brings in its train other factors such as available space, light, heat, etc. Let us consider a plant field which has just been started; and has in our case one shoot to a running foot. There is enough space and light for all the shoots to grow and multiply. At first the shoots have small slender leaves occupying but little space, but as the shoots become adult or begin to form millable cane the leaves become broad and big. There is not enough space for all of the shoots to get their share of light. Some of the better placed shoots continue to grow and others are starved, smothered out of existence. This is about the time when we notice the first big mortality in the number of suckers. This fact operates independently of the season, for in both March and September plantings the mortality starts between 4 and 6 months, about the time when millable cane is forming. However, in one case this period comes in the fall months and in the other in the spring and summer months.

After the first big wave of mortality there is a period of fairly stable conditions. Those stalks that have survived continue to grow. Then the time comes when the big canes, being top heavy, begin to lodge. The stable conditions are again altered and where the light penetrates the cane rows new shoots spring up. (Perhaps we should attribute this to the heat that comes with light rather than light *per se.*) If the trash covering is heavy these second-season suckers may not be very numerous. Nevertheless, these suckers are a reality. These new suckers get off to an excellent start, and are very soon competing with the old and fallen cane for light and air. In this struggle sometimes the old ones, but more often the younger ones, survive. It is now the turn of the old cane to begin dying from the top downward. Here begins the commonly observed rotting of the old cane. This picture is well supported by the data on shoot counts and by observations made at the time of harvest.

V. Number of Stalks Per Foot

It will be noticed that both in the March- and September-planted cane, the number of stalks per line is about 95 to 100 or about 2.7 per foot. This figure is essentially the same as reported previously by various workers in these Islands. But the point of interest is this, that in the March-planted cane, the maximum number was higher both in the outside and the inside lines than in the September-planted cane, but at 12 months and thereafter both plantings had the same number of stalks per line. On the one hand, it appears as though H 109 under the experimental conditions can support no more than 2.7 stalks per foot of line: as though the leaves of these stalks fully utilized all the light and air that are avail-

able over a foot of soil, leaving no room for further leaf production (in canes with smaller leaves this number should undoubtedly be greater). On the other hand, it raises the question: Is it of any advantage to have a large number of suckers to start with if we always end with the same number? Is the March planting better than the September planting?

Sucker mortality is a natural phenomenon and we shall not possibly be able to stop it, but nevertheless the writer feels that this is at best a necessary evil, necessary in the sense that a large sucker growth seems to be correlated with that much-sought-after quality of cane—namely, vigor; and evil, because in the opinion of the writer, sucker mortality represents much wasted effort and very probably some wasted material.

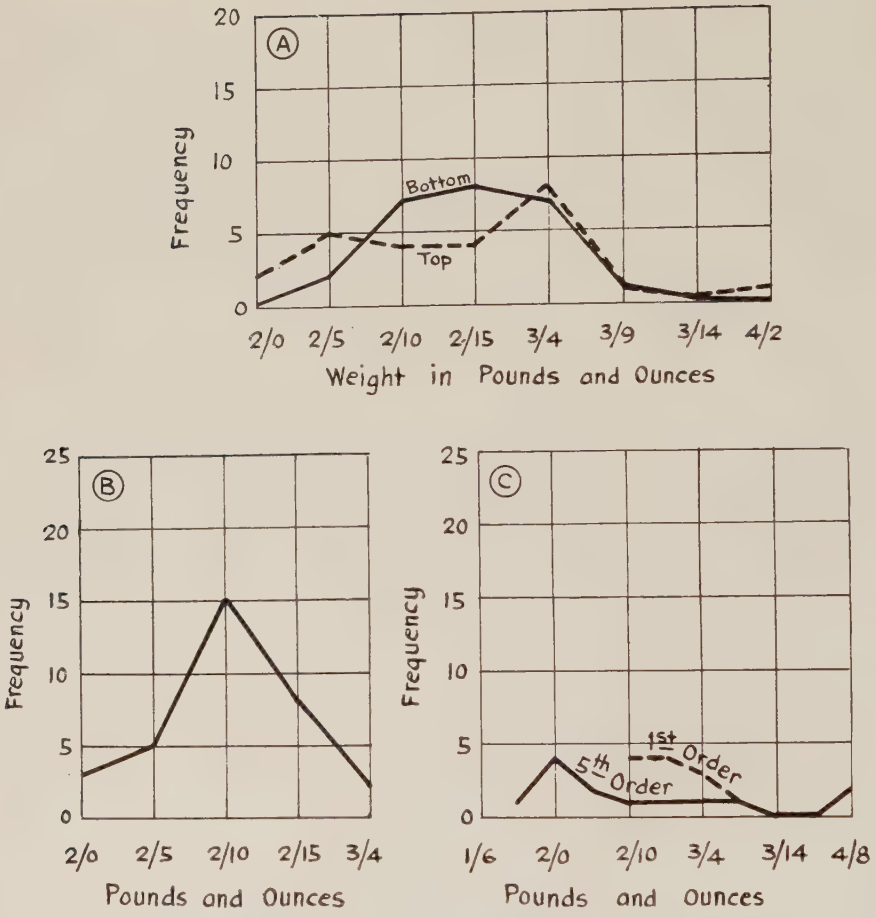
VI. Border Effect

Fig. 3 shows that a change in the exposure outside of the field affects the outside lines only. Even the first inside lines of March-planted cane do not show the same fluctuations as the outside lines. It would, therefore, appear as though one single line of cane was well able to protect an inside line from extraneous influences of exposure.

VII. Variations in Stalk Weights—An Index of Variable Field Conditions

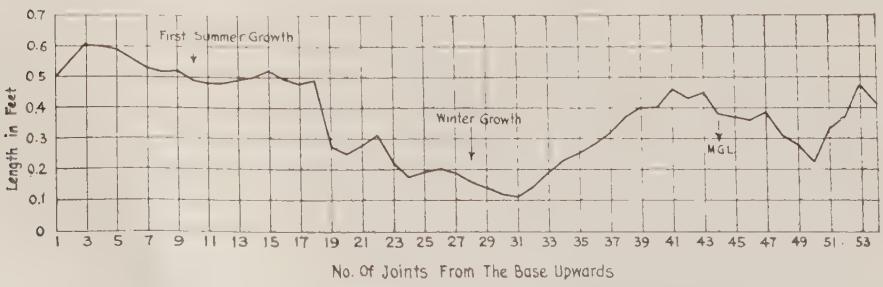
It has been previously stated that one is always confronted with great variations in studying sugar cane. Variations have been noted in the nature of suckering and number of suckers. We shall now discuss variations in weight which are to be found in various parts of the same stalk. We shall consider this aspect of quality of the different parts of a stalk at a later stage when we take up the question of juice quality.

If we take the weight of the bottom four feet of cane of the first-order stalks, we find that it is less variable from stalk to stalk than the top four feet of millable cane of the same stalks (Fig. 4). In one harvest, at 18 months, the coefficient of variation of the bottom parts was 0.23 pound and of the top 0.53 pound. In another harvest, at 25 months, the figures were respectively, 0.19 pound and 0.29 pound. Similarly, we find that the second-order stalks have more variation within themselves than the first-order stalks, and each higher order is more variable within itself than the orders preceding. The picture which we get from these data is this: When a field of plant cane starts we have a relatively small number of shoots. Each shoot has ample space to grow, ample plant food, etc., and consequently all can grow about equally well. But as the stalks grow big and new numbers arise to compete for light and food, some are placed to advantage and some otherwise. Some have probably lodged, and before they can come to unobstructed light others have crowded into the space, leaving the former to eke out a mere existence. Greater proximity to plant food, freedom from disease, etc., are also contributory causes to this variation. In other words greater variations in growth at later stages reflect greater variability of growing conditions within the field.



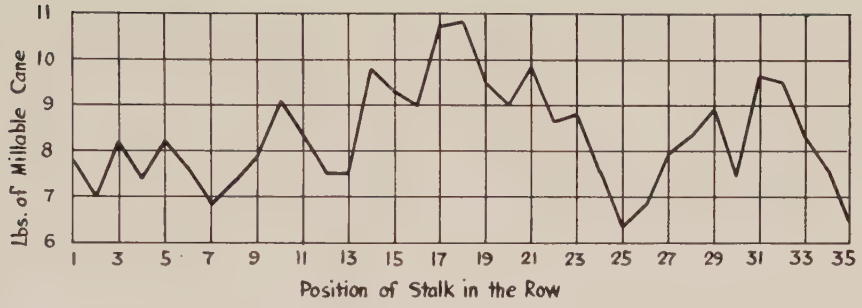
A—Top and bottom 4-foot lengths of first-order stalks.
B—Second-order stalks, same line.
C—Fifth-order stalks and bottoms of first-order stalks in the same stool.

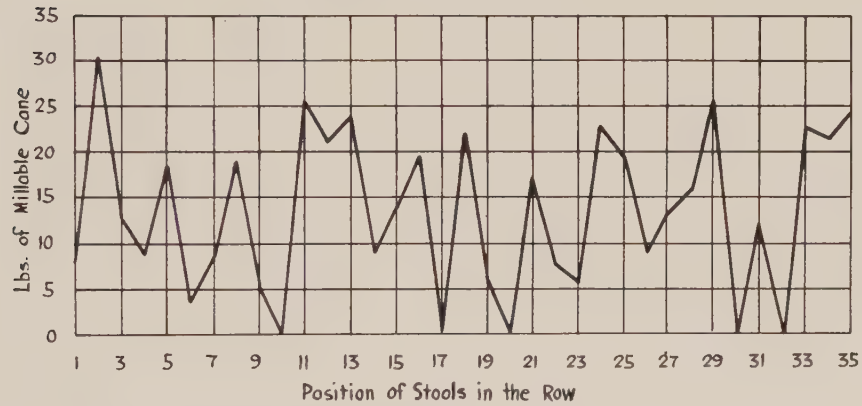
Fig. 4. These figures attempt to show that as the crop proceeds, growing conditions become more variable inside a cane field. The weight of the bottom 4 feet of the first-order stalks shows a normal distribution suggesting more or less uniform growing conditions. The weights of the top 4 feet of the same stalks are more variable as a result of variable conditions. The second-order stalks show a little more variability than the first-order stalks, while the fifth-order stalks which had their existence entirely under variable conditions show even greater variation in weight.



Length of each successive joint of a second-order stalk.

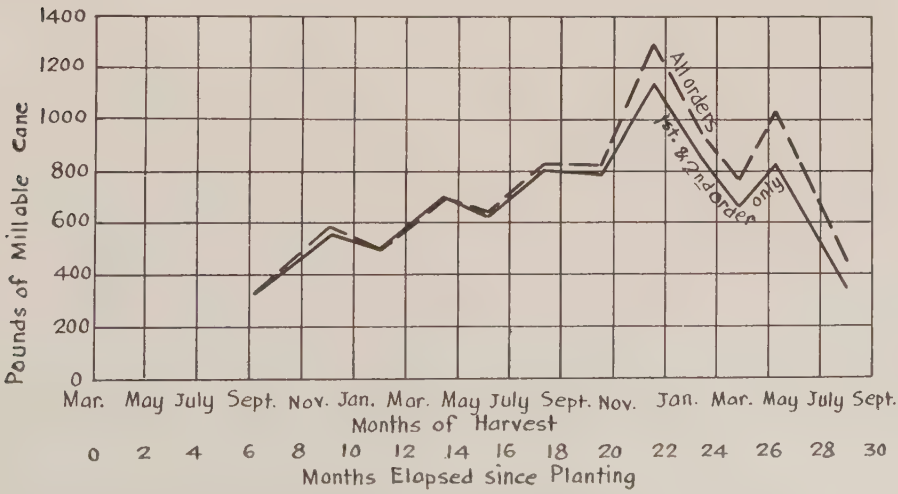
Fig. 5. Showing the variations in the length of joints caused by the seasons of the year. These variations are the usual rule in a cane field.





Showing the variation in the total weight of second-order stalks in the stools, the primary stalk weights of which are shown above.

Figs. 6 (above) and 6-A (below). In this particular experiment, in spite of careful plans working towards a uniform stand, we still find a great deal of variation in the weight of successive first-order stalks and of second-order stalks in successive stools of cane.



The proportion by weight of first- and second-order stalks in the total weight per line. (March planting.)

Fig. 7. First- and second-order stalks composed from 80 to 100 per cent of the total weight of millable cane harvested in this plant field. Under the experimental conditions, the second-season suckers play a minor role.

Probably no two internodes of sugar cane are ever alike in length or weight, influenced as they are by seasonal and other factors. Those of us who are familiar with the cane plant know of this seasonal variation. A typical example of the joint-to-joint variation in length of successive internodes of a stalk can be seen in Fig. 5.

This was a second-order stalk of March-planted cane harvested in September at the age of 18 months. It is quite evident from the chart that during the first summer the joints were long, they were shortest during the winter and they lengthened again the following spring and summer.

Fig. 6 shows variations in the weight of millable cane of first-order stalks from the same line, and Fig. 6-A of the second-order stalks from each successive stool of cane, also of the same line. In the case of second orders, the variations are naturally due to weight of stalks as well as number of stalks, for neighboring stools seldom have the same number of second-order stalks. And so we may go on giving instances of variation which are encountered at every step, all of which makes a study in crop variation a complicated task.

VIII. Millable Cane

March planting: Beginning at six months of age and about every two months thereafter, one or two lines of cane were harvested. At each harvest the stools were cut one at a time and the stalks of different orders segregated. The stalks of the same order in each stool were then weighed separately. Thus we have very detailed data on weights of millable cane and non-millable top in every line at each harvest.

Proportion of stalks of first and second order: In the experiment as planned and carried out* we find that the first- and second-order stalks average about 80 to 100 per cent of the entire number of stalks harvested at any one time and Fig. 7 will show that these stalks compose an even greater per cent by weight of the total cane harvested. For an evaluation of the crop progress in this experiment we need, therefore, consider in detail only the stalks of the first and second order—that is the stalks which came out within the first three months after planting.

Weight of millable cane of first and second order: Table IV and Fig. 8 show the weight of millable cane at various ages and seasons of harvesting. In the first-order stalks the cane weight increases steadily to about 22 months and is followed by a rapid decline, so that the weight of cane at 29 months is less than at 7 months. The weight of the second-order stalks also increases, but with less consistency, to a maximum at about 22 months and declines thereafter quite as rapidly as in the first-order stalks. An analysis of the harvesting data shows the fluctuation in the weight of the second-order stalks at various ages to be caused by variations in the number of stalks harvested rather than by their weight. Elsewhere we have remarked that with all our care and planning, we have been unable to make the different lines of cane contain a uniform number of stalks. However, the trend of increasing yield is so evident that we may overlook these fluctuations as the unavoidable experience of field culture.

* We use the words "as planned and carried out" advisedly. We do not know what the proportions would have been if the original stand were thicker or thinner.

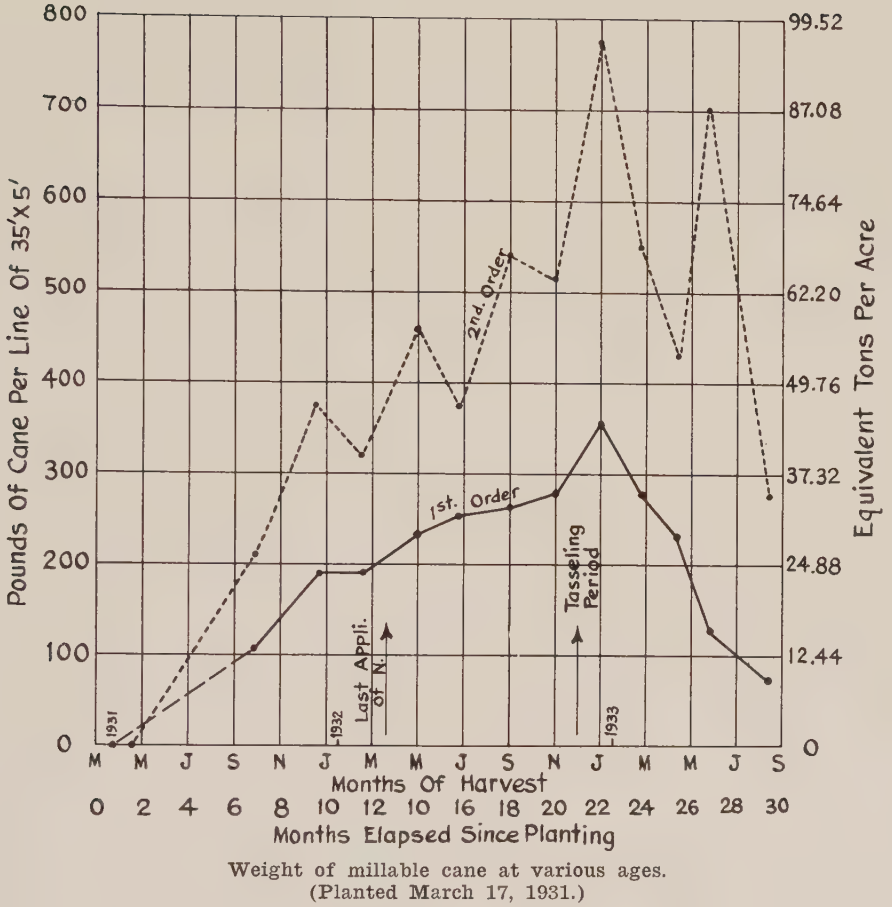
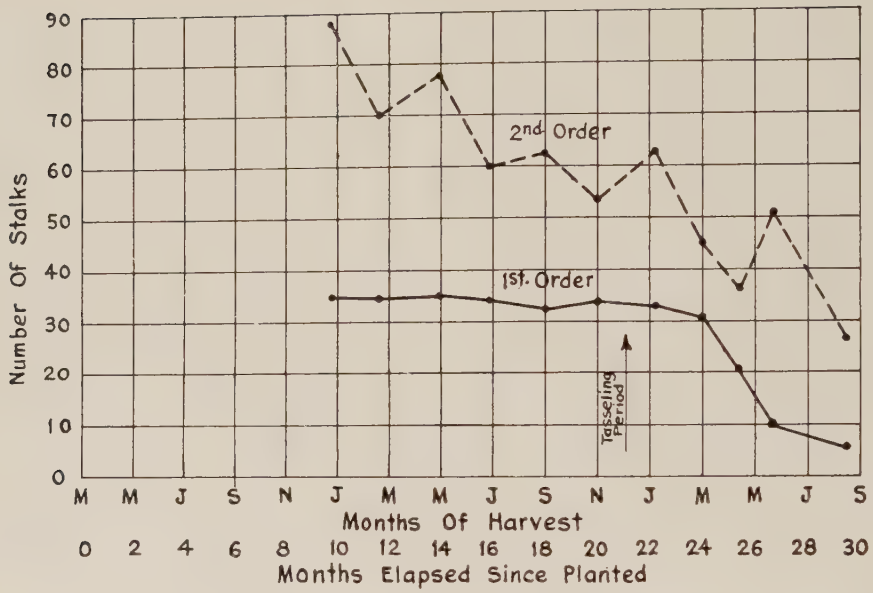


Fig. 8. The total weight of first- and second-order stalks rises steadily to an age of about 22 months, followed by a rapid decline. It is suggested that the decline is due to the field going back after tasseling. The fluctuations in the weight of the second-order stalks are caused by fluctuations in the number of stalks harvested.

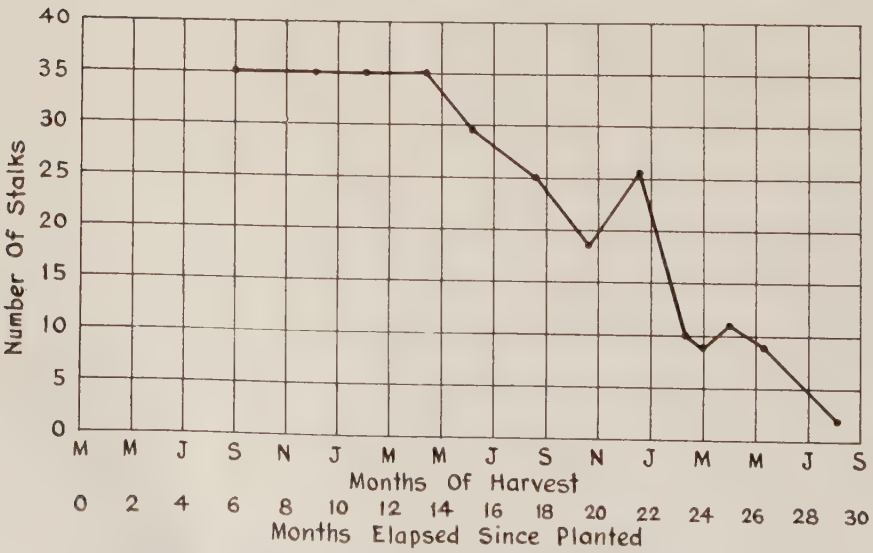
Discussion: The rapidity of the decline in cane weight after the January, 1933, harvest at about 22 months of age, has been due to the steadily mounting mortality of stalks, as will be seen from Fig. 9.

As a probable explanation of the cause of this mortality we offer the following: In this planting there were practically no tassels in the first year, but the following November (1932) the field tasseled very heavily. Tasseling as we know brings to an end the terminal growth of the stalk. The stalk has no actively assimilating leaf surface of its own. It must either gradually deteriorate or survive only if the terminal nodes can send out lalas (or side shoots) which can carry on the process of assimilation, thereby keeping the tissue in the mother stalk in a healthy condition. Very few lalas were, however, noticed on the March-planted cane and it is our belief that the majority of the stalks started inevitably to deteriorate because they were unable to send out lalas. This absence of lala growth may be traced to the lack of vegetative vigor in this 22-month-old field of cane. It will be remembered that our last application of nitrogen went in at 12 months of



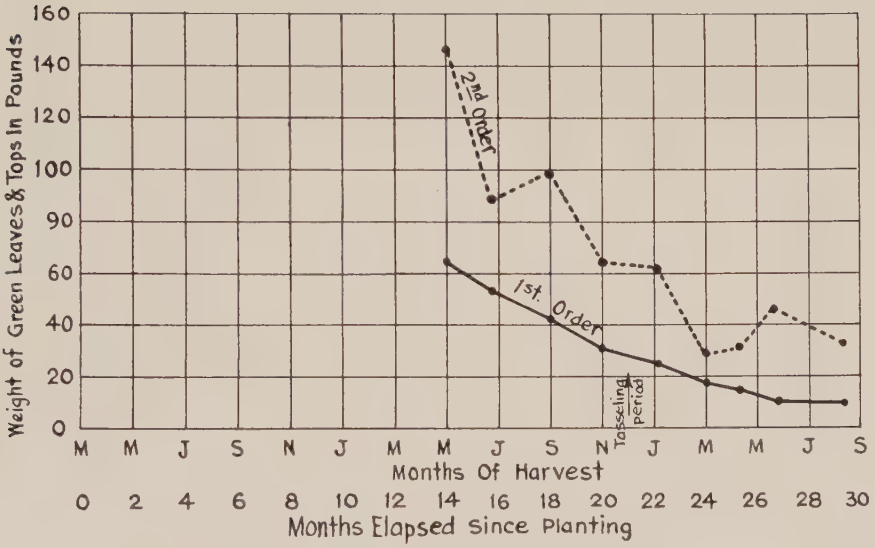
Number of stalks harvested per line on various dates.

Fig. 9. The number of stalks gradually decreases as the field gets old. Note the rapid decline in number after the twenty-second month resulting from mortality after tasseling.



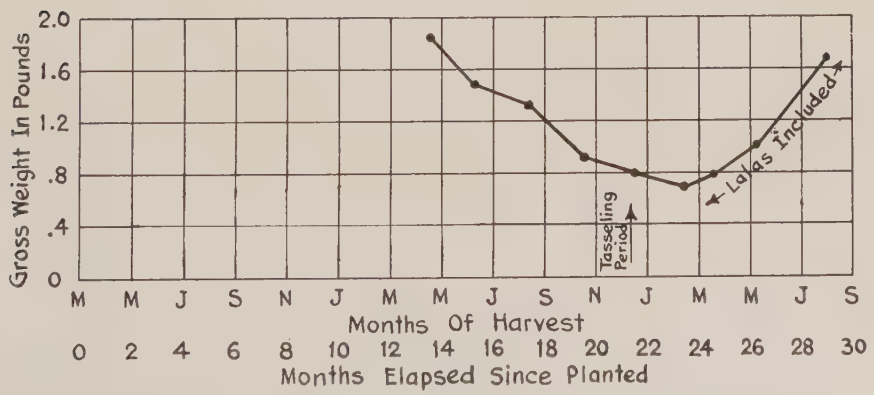
Number of healthy primary stalks harvested at various ages. Original number, 35.

Fig. 9-A. Deterioration of first-order stalks appears to start at about 14 months. This deterioration is probably due to plant competition accentuated by the declining vigor of some stalks due to old age.



Showing the weight of green tops at different ages.

Fig. 10. The weight of green top is highest in the first year of the field. Under experimental conditions the weight decreases steadily indicating decline in vegetative vigor.


Gross Weight In Pounds
2.0
1.6
1.2
.8
.4
0
Tasseling Period
Lalas included
M M J S N J M M J S N J M M J S
Months Of Harvest
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Months Elapsed Since Planted

Average weight of green top of primary stalks. (March planting.)

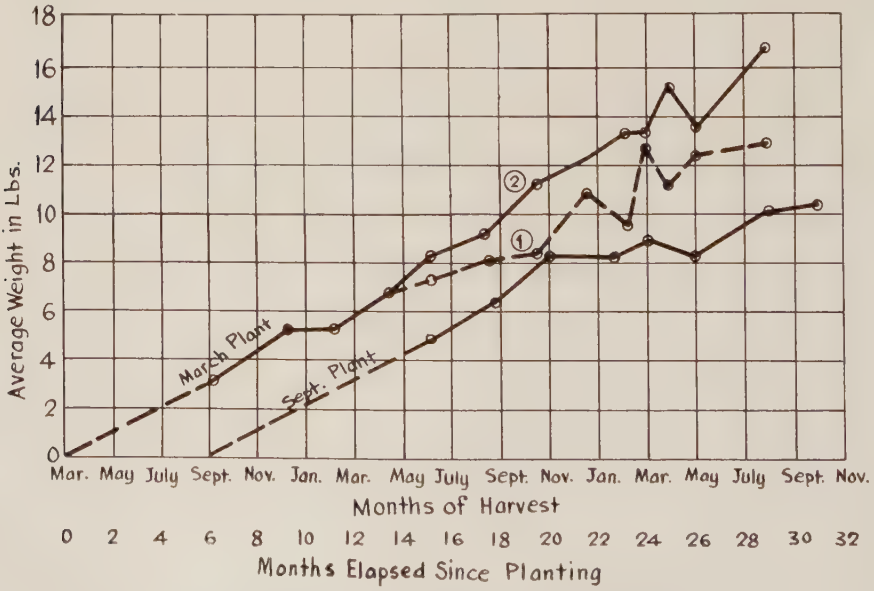
Fig. 10-A. The average weight of green top on a first-order stalk decreases very rapidly in the second season. After tasseling there is an apparent increase caused by lalas.

age or fully 9 months previous to tasseling. The declining weight of non-millable green tops at various ages (Fig. 10) also supplies additional evidence in support of our statement concerning lack of vigor.

Number of stalks at various ages: Table V and Fig. 9 show the number of stalks harvested at various ages. We see at once how rapidly the number goes down, especially after November, 1932, i.e., after tasseling. Excluding the stalks which were partly decayed, we find the picture even more striking (Fig. 9-A). Deterioration appears to start in the first-order stalks between 14 to 16 months of age and from then on it proceeds rapidly so that at the age of 29 months we have out of 35 original stalks only two which were entirely healthy. However, this deterioration is a more gradual process than the rapid decay which follows tasseling.

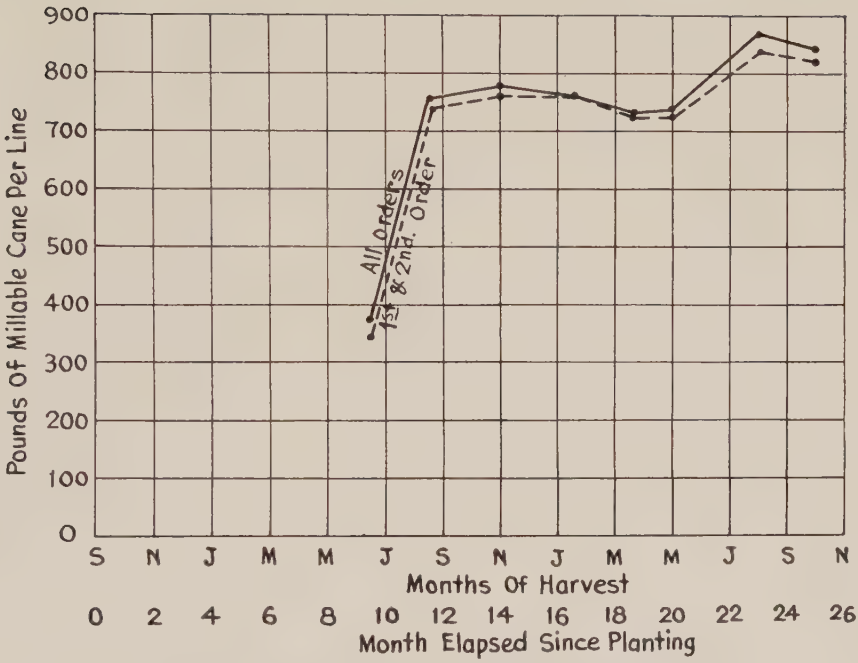
Weight of green top: In Table IV and Fig. 10 we see that the weight of green top also declines rapidly as the cane grows old (we did not keep data on green top prior to April, 1932). This decline is due to the decrease in the number of stalks as well as the average weight of the top of a single stalk. Table VI and Fig. 10-A shows that the weight of green top of an average primary stalk fell lower than 0.7 pound of weight at 23 months from a value of 1.8 pounds at about 14 months. After 24 months there is apparently an increase in weight again in the few surviving stalks due to the green weight of lalas.

Average weight of first-order stalk: Table VI and Fig. 11 show the average weight of a first-order stalk at various ages. The weight goes on steadily increasing at first and then there is a tendency for the curve to flatten out as large num-



Average weight of primary stalks at various ages.
1—Inclusive of cane with dying tops.
2—Exclusive of cane with dying tops.

Fig. 11. Increase in the weight of the first-order stalks appears to be uninterrupted to an age of 29 months. Decrease in the total weight therefore results from loss of number rather than the weight of stalks.



Total weight of millable cane in all orders of stalks harvested at different dates compared with the weight in the first- and second-order stalks only.

Fig. 12. In September-planted cane second-season suckers are almost non-existent, the first- and second-order cane forming over 95 per cent of the total crop.

bers of partly deteriorating cane are being included. If, however, we confine our analysis only to those stalks that carry a healthy top, we find that the increase in weight is quite steady to the age of 29 months.

September planting: Similarly as in March planting, one line of cane was harvested at intervals of about 2 months beginning at the age of 9 months.

Proportion of first- and second-order stalks: First- and second-order stalks in September planting constitute an even greater proportion of the total weight and number of stalks per line than in the March planting (Fig. 12). Whereas in the March planting we had at times 10 to 12 per cent of the total weight in second-season stalks, in September planting we had at no time more than 2 per cent in stalks other than first and second order. This difference in the crop composition of the two seasons of planting is of interest and may under certain circumstances be of significance.

Weight of millable cane: Table VII and Fig. 13 show the weight of millable cane harvested at various ages. In contrast to the figures presented for March-planted cane, here the weight increases up to about 14 months and then there follows 6 to 8 months of no increase or decrease and a very slight increase thereafter at 22 and 25 months. The sudden jump in the weight of second-order stalks around 12 months is due to an unusually large number of stalks of that order being harvested at that time. If we allow for this variation in number, we find the total weight of the second order to be about 100 pounds less.

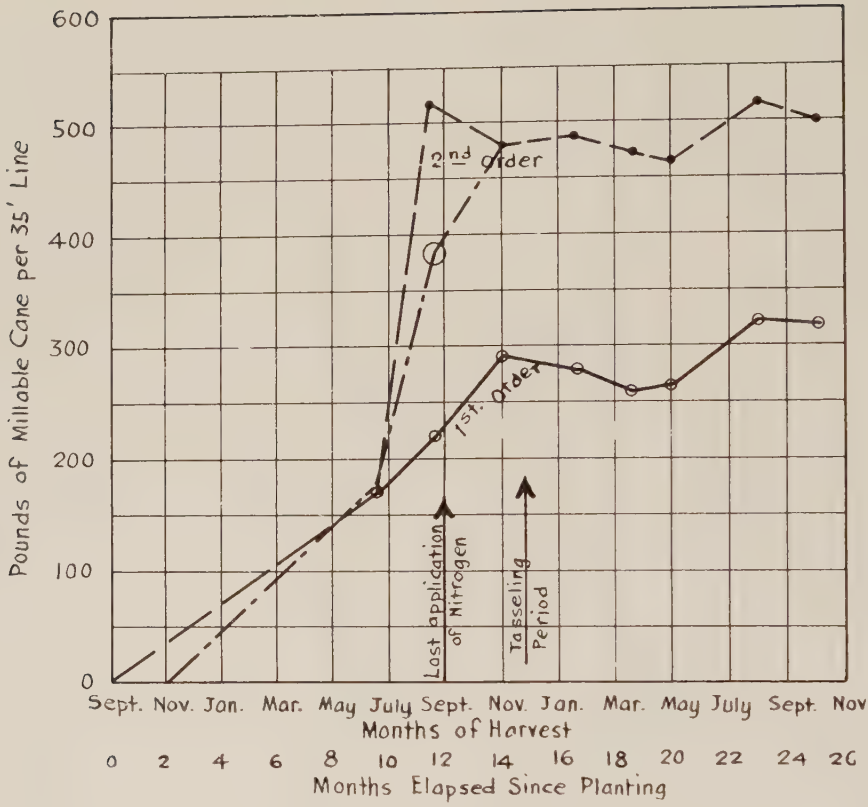


Fig. 13. Contrasted with the March-planted cane, there is hardly any increase in weight of cane harvested after about the fourteenth month. We believe that this static condition is also due to the effects of tasseling. As the lalas become millable there is a slight increase after the twentieth month.

Discussion: These results further support our contention that the effect of tasseling and the time of last fertilization have an important bearing on crop yield. This cane, planted in September, 1931, tasseled in November, 1932, or at the age of about 14 months. Only two months previously, or at the age of 12 months, the plots had received their last application of nitrogen, at the rate of 50 pounds per acre. As opposed to the March-planted cane, this September-planted cane still had much vigor left (as the weight of green tops will indicate), with the result that these canes sent out lalas soon after tasseling and managed to survive. We have actually observed more lalas in this cane than in the March-planted cane. Most of these lalas formed millable cane later and this fact explains the slight increase in yield at about 22 months of age and thereafter. There were 6 to 8 months of static condition during which period no millable lalas were being harvested. It is our belief that in this plot a large number of tasseled sticks were standing still while the lalas were slowly coming to be millable and in the case of the remaining stalks the natural deterioration of some stalks was offset by the increase in weight of others so that the net gain was still nil. Even though the greatest total weight of cane was harvested at 23 months, there is no question that a plantation would have been justified from considerations of per-acre-per-month value to harvest a sim-

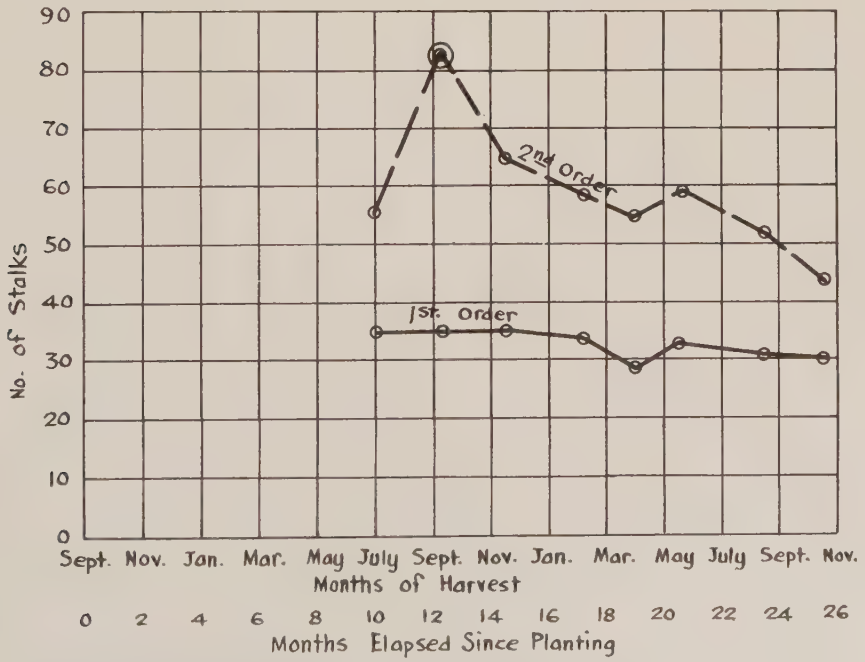
ilarly affected area at about 14 to 16 months of age or soon after tasseling. By so doing the unproductive months that followed tasseling could have been utilized in growing a good ratoon crop.

It must not be understood that we are bringing up here the issue of long or short crops, a much broader question and one which involves many other factors. Tasseling alone may not determine whether to cut a field long or short, for there may be ways and means by which even tasseling or its after-effects could be controlled.

Our results suggest that a close study of the condition of the field and better knowledge of how to interpret what the cane crop has to tell us may be very helpful in settling some of the moot points bearing on the proper length of crop.

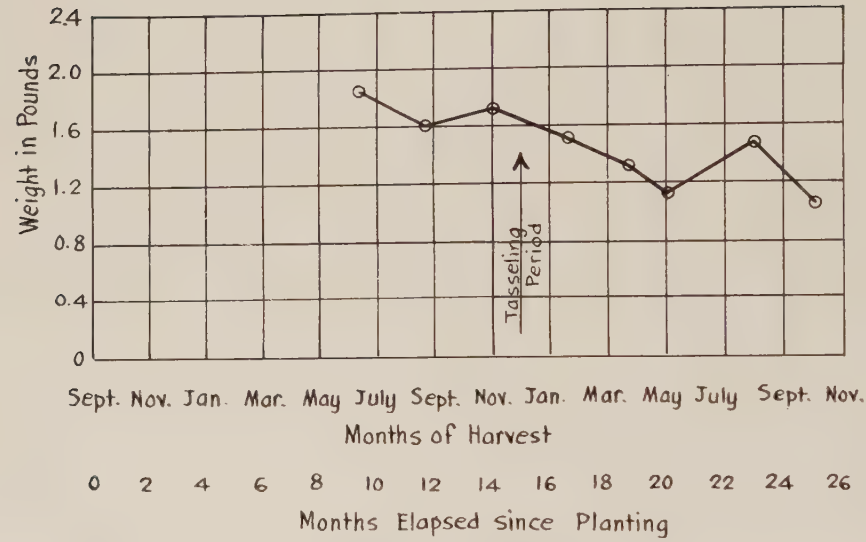
Number of stalks at different ages: Table VIII and Fig. 14 show that the number of stalks harvested does not fall off as rapidly in the September-planted cane as in the March-planted cane. We would expect this to be so, knowing that rapid emergence of lalas after tasseling had kept the big cane from deteriorating.

Weight of green top: In Table IX and Fig. 15 we see that the weight of green top decreases similarly to March-planted cane from a high value to about 1.8 pounds per average first-order stalk at 9 months of age to a little over 1 pound at 25 months. At no time does the value fall as low as 0.7 pound—the lowest value for March-planted cane. Just prior to tasseling the average stalk had a top weighing 1.6 pounds. In March-planted cane the top was less than 1 pound at that time—



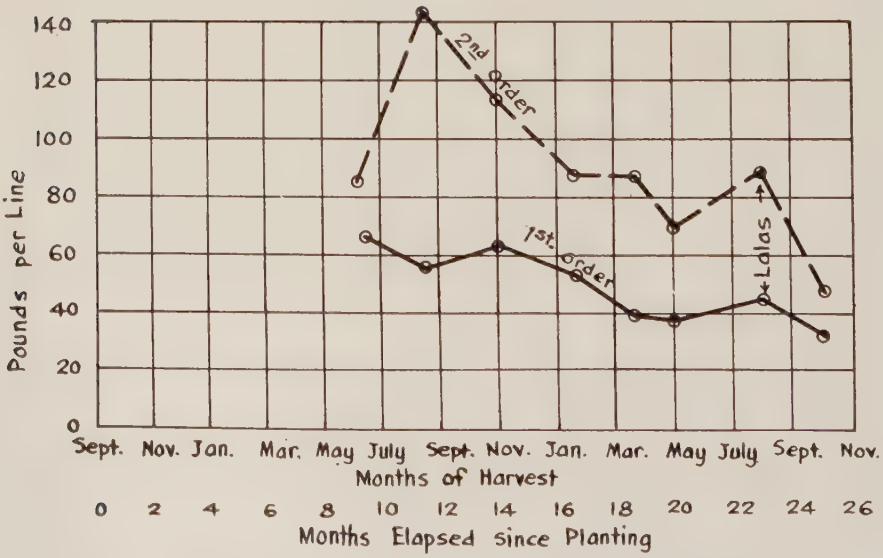
Number of stalks harvested on different dates. (September planting.)

Fig. 14. In this planting the number of stalks does not fall off in the manner observed in the March planting. It has been suggested in the body of the report that this difference may be attributed to the time of application of fertilizer in relation to the season of tasseling.



Average weight of green top of first-order stalks. (September planting.)

Fig. 15. Note that at no time the average green weight of non-millable tops falls to such low values as were found in the March-planted cane.



Total weight of green leaves and tops. (September planting.)

Fig. 15-A.

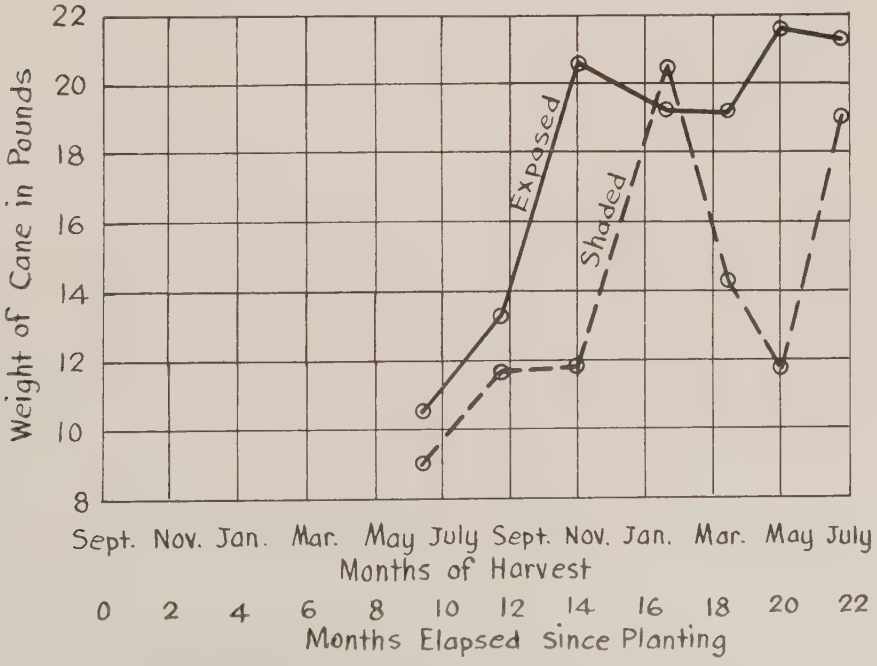
again supporting our belief that the September-planted cane had greater vegetative vigor.

The total weight of green matter per line is seen, as in the other planting, to be highest when the cane is about 9 months old, the weight decreasing steadily thereafter (Fig. 15-A).

Shaded vs. exposed cane: In connection with suckering, we stated the fact that one end of section E of September-planted cane was shaded in the mornings by an adjoining field of cane with the result that this end was delayed in suckering and was otherwise weak at the start. In harvesting this plot we always separated the exposed end of the plot from the shaded end, so as to study the variations at different ages. Table X and Fig. 16 show that the weight of cane in a running foot of row in the shaded section was much lower, with one exception, than in the exposed section. (It should be stated that shading by the adjoining cane ceased to be a factor when the September-planted cane grew big. After the first 8 or 10 months, there was therefore no shading effect to speak of.) These results would suggest that the tremendous handicap of a poor start can not be wholly made up by equal conditions later on.

IX. Juice Quality

The problem of juice quality is even more complicated than problems of cane weight. Juice quality is affected by all the factors that cause variation in cane weight and many more. The average quality of juice from a field of cane is



Average weight of millable cane per stool (one-foot row) in the shaded and exposed parts of the same line of cane.

Fig. 16. Plants that were shaded for several months early in life weighed less than those plants that were continually exposed.

usually a composite of all the different orders of stalks growing in the field. The proportion by weight of the different orders and their respective quality will then be the determining factors.

Then there are other factors such as variation in quality in different parts of the same stalk, the effect of tasseling and forming lalas, the effect of season and weather conditions, cultural practices, etc. If the problem is more complicated, then the need for precise knowledge leading to an understanding of it is also greater. In the following pages we shall first take up a general discussion of the average quality in the whole stalks, to be followed by a detailed discussion of quality in different parts of the stalks.

Method of extraction and definition of quality: At each harvest the different orders of stalks were made into composite samples and the total weight of cane was run through a three-roller Cuba Mill having an extraction of about 50 per cent of juice. By so taking the total weight, sampling errors were avoided. The juice samples were then analyzed by the Sugar Technology Department of the Station for Brix, polarization, sucrose, glucose, and purity. Juice quality in this paper refers primarily to the percentage of sucrose and glucose in the juice, as these two quantities are generally sufficient for an understanding of the true quality of cane.

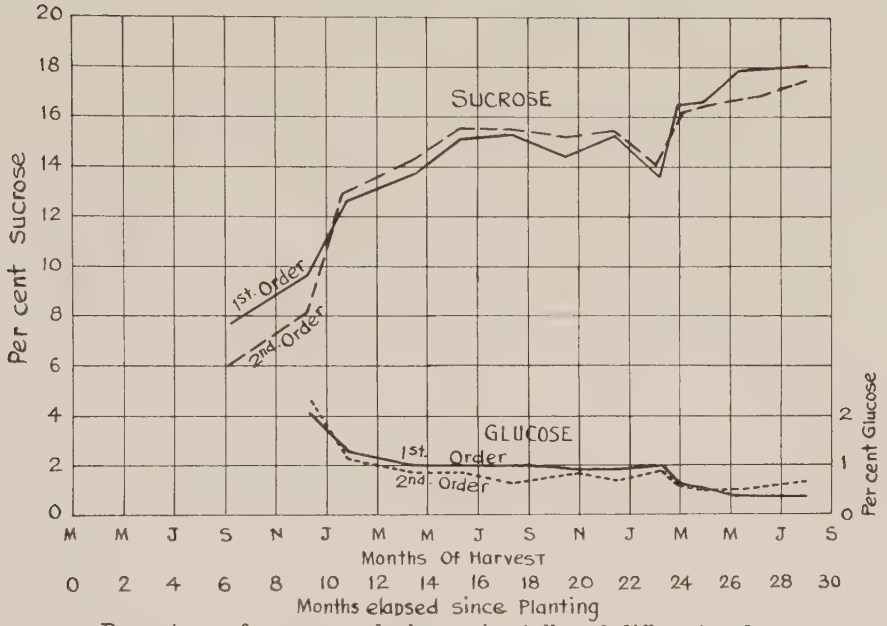
March Planting:

First- and second-order stalks: Table XI and Fig. 17 show the per cent of sucrose and glucose in the different orders of stalks at various dates of harvesting. These figures show clearly that the per cent of sucrose goes on steadily improving to an age of 29 months. In cane more than 24 months old we have obtained juices of 16 to 18 per cent sucrose, of 93 to 94 per cent purity, and 7 or less quality ratio. (Quality ratio is the theoretical tons of cane required to produce a ton of sugar.) In other words there is no evidence to indicate that there is an inherent disposition in cane to deteriorate after it has grown for two years or more.* In this connection it must also be remembered that this excellent quality of juice was secured even without any attempt to "ripen-off" by withdrawing water from the cane for any length of time before harvest. The cane was receiving four inches of water a week to the very last day.

Stalks of higher order: In Fig. 18 we see that the stalks of third, fifth, and sixth order also improve steadily to the last. In fact at around 24 to 29 months after planting, these second-season suckers, meaning the stalks of fifth and higher orders, were just coming of age, so to speak, with a high percentage of sucrose in juice. The point of great interest is that these late suckers, contrary to our belief at the start of the experiment, proved to be capable of making as much or more sucrose than the first-season cane. With this variety and under the conditions of the experiment there is, therefore, no reason to fear lowering of average quality due to inclusion of well developed second-season suckers in our long plant crops.

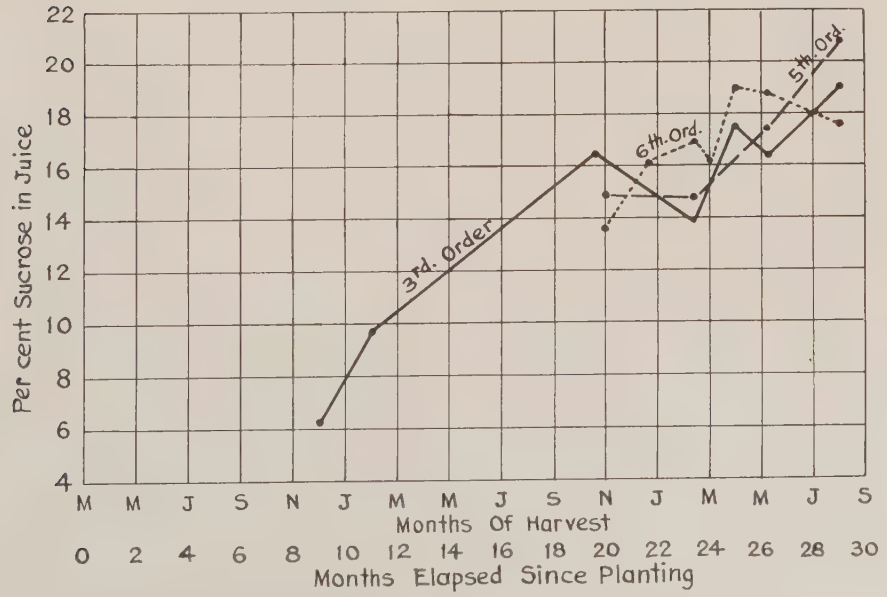
Percentage of sucrose in stalks of different orders at various dates: The data in Table XI have been so arranged in Fig. 19 as to permit ready comparison of

* In one respect our harvest probably differed from plantation harvests, in that we carefully excluded all deteriorated cane.



Percentage of sucrose and glucose in stalks of different orders. (Cane planted March, 1931.)

Fig. 17. In spite of a continuous application of 4 inches of irrigation each week and no attempt at ripening by withholding water, the quality of juice steadily increases to an age of 29 months. There is no indication of the gradual deterioration of juice due to the age of the cane stalks. Poor juices in old fields of cane may be due to dead and dying cane here excluded from consideration.



Per cent of sucrose in juice of third, fifth and sixth orders of sucker at various dates.

Fig. 18. Contrary to the generally held belief, the second-season suckers have been found to be quite as rich in sucrose as the first-season cane.

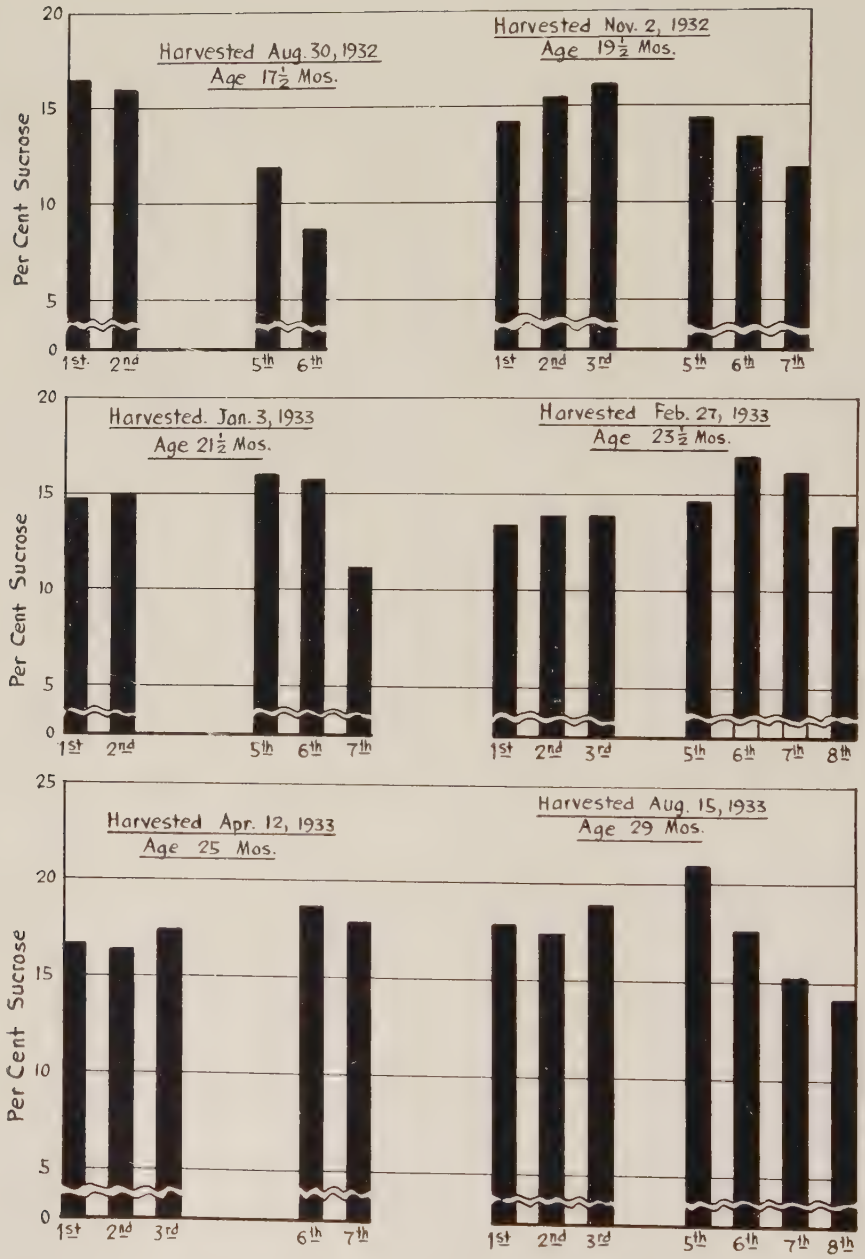


Fig. 19. Shows the percentage of sucrose in the juice of different orders of stalks at various ages. At 17 months of age the first-order stalks have the maximum sucrose content. At each successive harvest the maximum tends to shift to higher orders. (The harvest at 29 months is not quite normal; the field had deteriorated a great deal and the few surviving suckers were of poor appearance.) There also appears to be a trend towards a higher maximum as higher orders come to their peak.

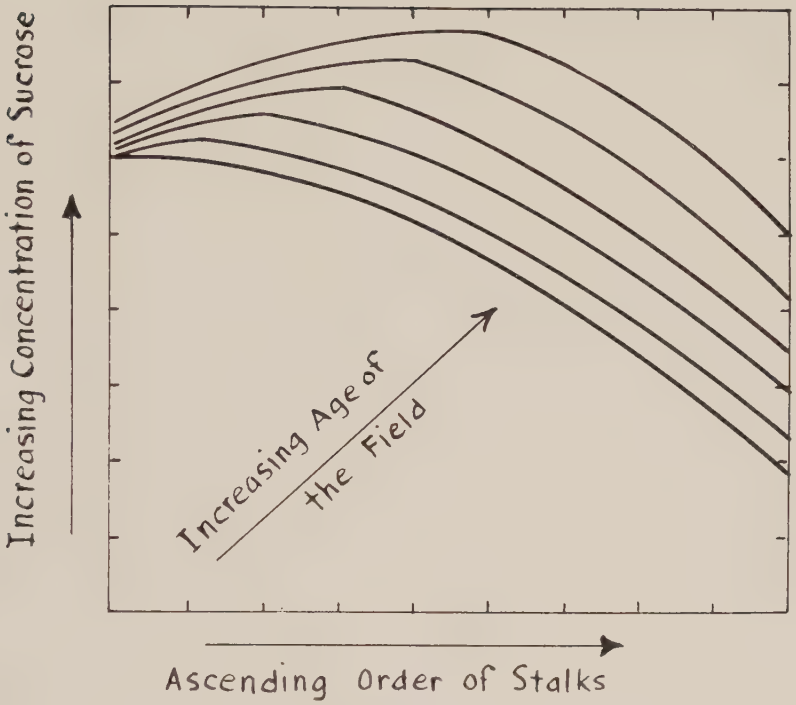


Fig. 19-A. On the basis of the results shown in Fig. 19, we here offer a simple diagrammatic scheme of the progress of sucrose accumulation in a field of cane under experimental conditions. The essential feature of the scheme is that each successive order comes to have the maximum sucrose in its turn and this maximum is probably a little higher than the one previous.

the percentage of sucrose, etc., in different orders of stalks at various dates of harvest from the sixteenth month on. In the first figure, the maximum sucrose content is found in the first-order stalk, two months later in the third-order stalk, and another two months later in a stalk of higher order and so on. Not only does the maximum point appear to shift from the lower to the higher order as time goes on, but also there appears to be a tendency for each subsequent maximum to be a little higher than the one previous. On the information provided by the meager data, we offer a diagrammatic representation of how the concentration of sucrose may vary with time in stalks of different orders (Fig. 19-A).

This diagram suggests that each order beginning with the first comes to its peak in turn. Thereafter its sucrose content remains more or less static—increasing or decreasing a little as the cane remains healthy or deteriorates. In the meantime the next order is rising to its peak, but the peak of the latter is slightly higher than that of the previous order. We believe it will be readily granted that our diagram is sound regarding the first point, that is, the order of time in which different orders come to maturity, but there will probably be hesitation in accepting the other point that each successive peak is higher than the previous. In partial support of our statement we draw attention to the following facts: Our joint-to-joint analysis of first- and second-order stalks shows that the top sections of the big cane have a higher concentration of sucrose than the bottom parts ever had. The development of the second-season suckers took place at the same time

as the top parts of the first-season cane. Could not the same conditions which make possible the higher concentration of sucrose in the top section of the first-season cane operate similarly in the case of the late suckers?

Secondly, we all know that in a field of cane each successive order of suckers is thicker and bigger than the previous ones. We explain this fact by assuming that the higher order avails itself of the materials elaborated by the previous orders of stalks in the stool and thereby gets an excellent start. May there not be some similar reasons why, under favorable conditions, each successive order should be capable of accumulating more sucrose than the ones previous? The scheme here proposed is not to be considered as final, but as something that should receive further study and thought.*

Differences in juice quality in the different parts of the same stalk: From a practical standpoint, the differences in the quality of the same stalk at different ages may be of even more significance than the difference between successive orders. How does a cane mature? Is the sucrose or glucose content the same in the different parts of the cane? How do seasonal influences or cultural treatments affect the various parts of the cane? With these thoughts in mind we harvested several lines of cane. At harvest we segregated the stalks of various orders and each stalk was divided into the following sections, working from the top downward:

(1) Non-millable top with leaves.
(2) Millable cane.

The millable cane was further divided into 4 sections:

(a) The green-leaf part.
(b) The top 4 feet of cane remaining after the removal of the green-leaf part.
(c) The extreme bottom 4 feet, i.e., 4 feet of cane directly above the ground.
(d) The section between b and c, hereafter called the middle section.

The green-leaf part is defined as that part of the cane where the attached leaves are still wholly or partly green. In actual practice the green-leaf part ended at a point where on removing the leafsheath no scar was left on the stalk. It is believed that since the green leaves are attached to this section only, this would also be the zone of most active sucrose accumulation. The results obtained appear to justify such belief.†

The cutting of cane according to the above scheme appears to have merit, especially for the purposes of fundamental study, over the general practice of cutting cane into equal sections working from the bottom upward. Let us consider the case of a sucker which is 8 months old and contains, say, only 4 feet of

* In comparing our results with those of workers in other countries one must remember that our crop is usually 20 to 22 months long and although we fertilize very heavily, the cane receives very little in the last year of growth. Our unique agriculture must of necessity give us different results.

† So far as we know, the sugar station at Coimbatore, India, was the first to suggest the value of separating the cane into green-leaf and dry-leaf sections for studying juice quality.

cane. In the more generally used practice we would be comparing the bottom of this young cane with the bottom of an old, say, 18-month cane. One can easily see that the comparison would hardly be valid, for the simple reason that the two sections did not grow at the same time. In the present scheme, this sucker would have only a top section (for we shall work from the top downward) and this would be compared with the top section of an old cane. There is great probability that both these sections were growing at the same time and were therefore equally influenced by environmental factors. Thus it happens that where the length of cane is less than 8 feet we have obtained only top and middle sections—and from our point of view this cane consists of no section comparable to the bottom section of a 12- or 14-foot cane. The data are presented in Table XII and Figs. 20, 20-A and 20-B.

In regard to sucrose per cent, we see at once that in all stalk orders there is materially little difference in the different sections of the dry-leaf part of the millable cane (i. e., the part of millable cane without the green-leaf section), but

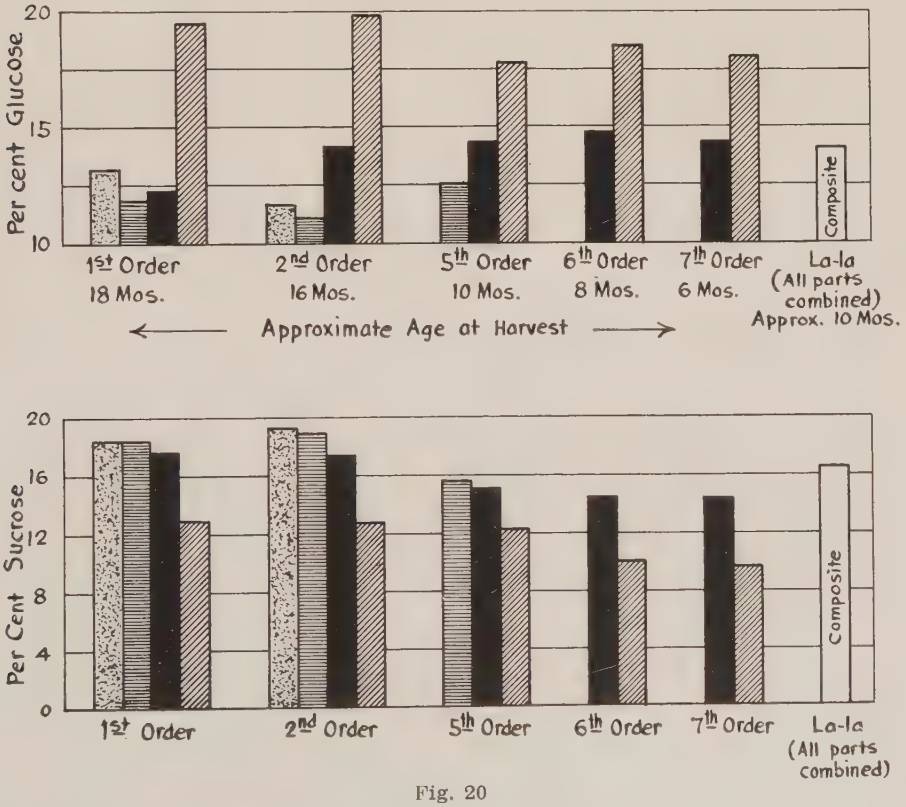


Fig. 20

Figs. 20, 20-A and 20-B. These three figures show that sucrose and glucose are more or less uniform throughout the length of the dry-leaf part of a cane. There is a sudden transition from the dry-leaf to the millable green-leaf part. The green-leaf section is therefore the only part of millable cane where active accumulation of sucrose is taking place. Even the top just below the millable green leaf has reached a state of maturity. It is also interesting to note that the point of maximum concentration of sucrose apparently moves from the bottom to the top as the field gets old. Actually, the bottom still remains the same while the top becomes richer in sucrose.

Note: In Figure 20-A and in subsequent figures "green leaves" and "dry leaves" should read "green leaf" and "dry leaf".

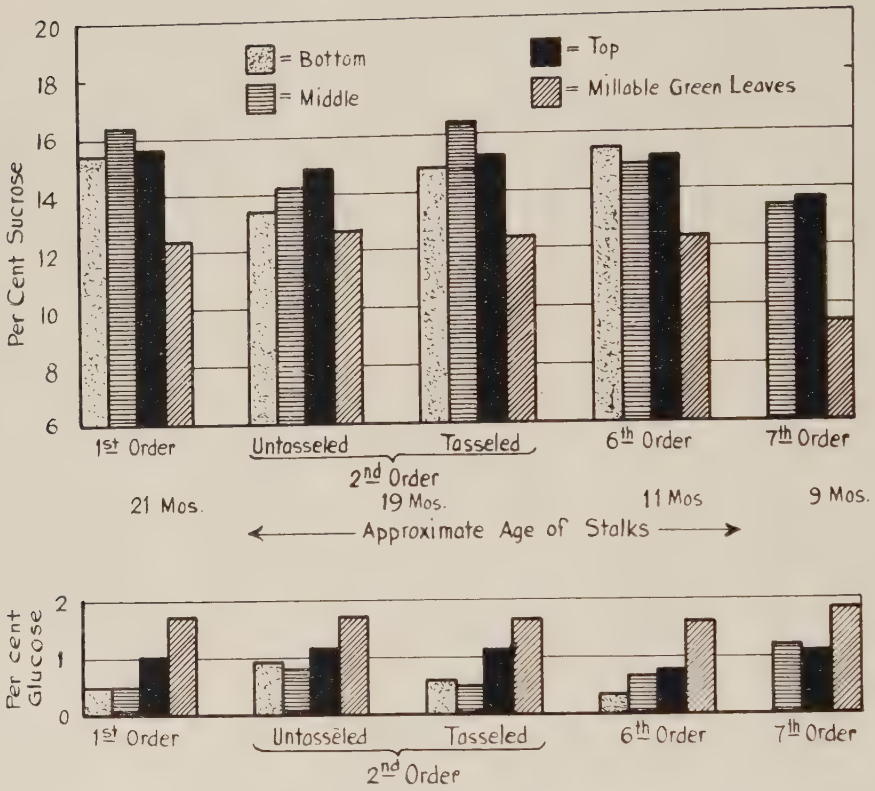


Fig. 20-A

(For legend, see Fig. 20.)

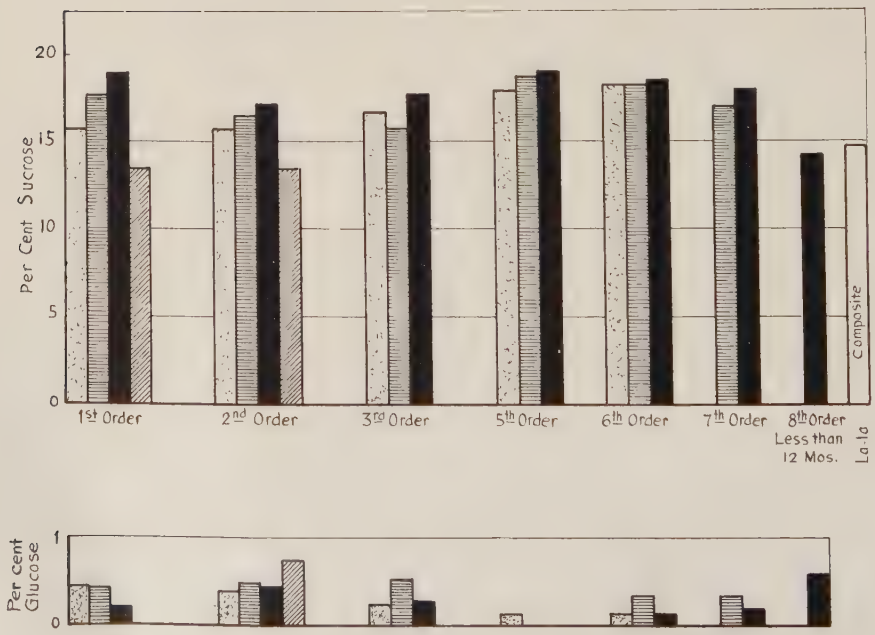
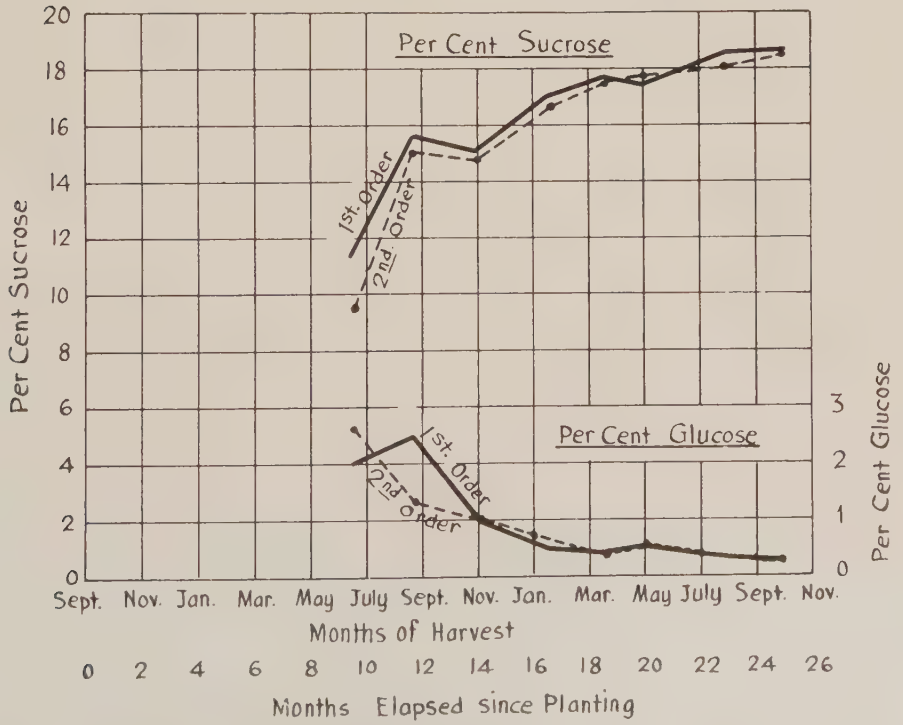


Fig. 20-B

(For legend, see Fig. 20.)

from there to the green-leaf part there is a sudden decline in sucrose content. In other words we may say that the green-leaf section is still in the process of gathering sucrose, while the dead-leaf part has reached a certain state of maturity. We do not imply that the level of sucrose in the dead-leaf part will not rise any further. In fact there are grounds for believing that it does rise to a small extent in young stalks, but what we do emphasize is this, that the green-leaf part is the one that is capable of the most advancement in sucrose; this is the part that is now growing and will be comparatively more susceptible to present environment and treatments than any other part.

The relative proportion of the green-leaf part to the dead-leaf section is therefore a matter of very great importance from a practical standpoint; for the average juice of a stalk is a composite of these two sections. The superiority of an old cane over a young sucker is undoubtedly due in a large measure to the fact that in young, vigorously growing suckers, the green-leaf part may constitute fully one-third or one-half of the whole millable stalk. In the old cane it may be, and generally is, about one-eighth, one-tenth or less of the whole stalk. Even if the sucrose content in the dead-leaf and green-leaf sections of the two canes were identical, we should find a great difference in the average juice quality of the two canes, much in favor of the older cane.



Percentage of sucrose and glucose in juice of stalks of various orders. (Cane planted September, 1931.)

Fig. 21. Similarly, as in March-planted cane, the quality of juice in this planting continues to improve to an age of 25 months.

One may therefore ask the question as to what actually happens when we withhold water from the maturing cane. We have seen that the dead-leaf section had reached a certain state of maturity long before harvest time and the accumulation of sucrose in that part was mostly influenced by conditions of environment and culture that are now past history. Could it not be that in ripening-off we are concentrating our efforts primarily on the green-leaf section? True, the withholding of water may drive off a small percentage of moisture from the cane, but probably the greatest thing it does is to stop new growth, and at the same time add more to the dead-leaf section by reducing the size of the green-leaf section.

Point of maximum sucrose content: When the field was harvested at 18 months of age, the maximum concentration of sucrose was still in the bottom section. Three months later the middle section appeared to have the maximum concentration in several orders of stalks; and another 5 months later, or at the age of 26 months, the maximum sucrose content appeared to be definitely located in the top section. This does not necessarily mean that the bottom section had deteriorated rapidly since the first harvest at 18 months. In fact our data show that the bottom part had remained practically still, but it was the top part which had come up considerably in sucrose.* Theoretically there is no reason why there should be a great deterioration of sucrose in the bottom part of a healthy stalk of cane. If sucrose must break down into reducing sugars to supply the respiratory needs of the bottom joints this demand can be only very small.† This improvement in the top part may be due to environmental conditions of weather or culture or to some physiological reasons. We shall take up this point in discussing the detailed joint-to-joint analyses.

Glucose in the various parts: As in the case of sucrose the concentration of glucose also changes suddenly as we move from the dead-leaf to the green-leaf section. This sudden increase in the amount of glucose in the green-leaf section again points to the conclusion that this is the part of the cane where active processes are still going on.

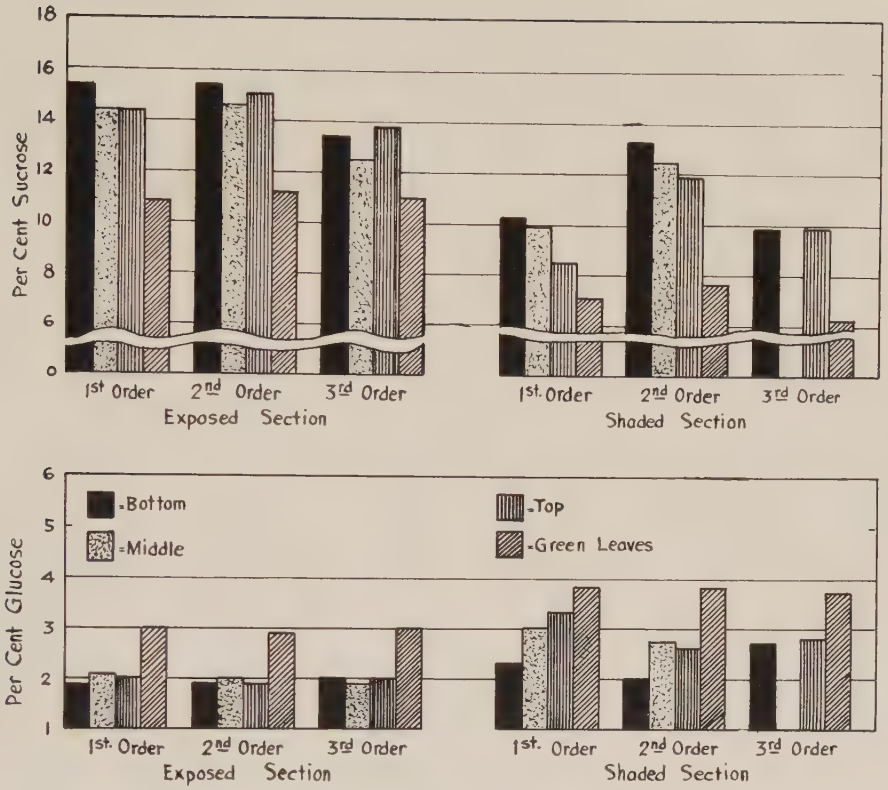
September Planting:

Juice quality in the first- and second-order stalks: In Table XIII and Fig. 21 we see that here also the per cent of sucrose rises steadily to 25 months. Here also there is essentially no difference between the quality of the first- and the second-order stalks after the first few months.

Exposed vs. shaded plants: Fig. 22 shows the juice quality of exposed and shaded plants in the harvest at 15 months. The other harvests also show similar differences. The exposed plants have generally a higher percentage

* The harvest at 18 months was from an outside line and therefore should not be compared with the results of the two later harvests which were from inside lines only. Our detailed juice analysis data shown elsewhere in this paper fully support the statement just made.

† In this connection it may be of some interest to study the concentration of the enzyme invertase in different parts of 18-month-old stalks. Dr. Constance E. Hartt of this Experiment Station who is responsible for these determinations finds that in 18-month-old cane the invertase concentration drops from a level of about 20.0 (expressed in cc's of N/20 $KMnO_4$) in the growing point to 8.9 in the green-leaf part and down to only 1.3 in the bottom joints. In other words the invertase activity is so low in the bottom part that we need fear no great breakdown of sucrose—barring mechanical or other injury leading to active deterioration of tissue.



Comparing the juice quality of exposed and shaded sections. Harvested November 30, 1932. Age about 15 months.

Fig. 22. Fig. 16 showed that the shaded plants always had less weight of cane than the exposed plants. This figure shows that the same applies to sucrose concentration in the entire cane including millable green-leaf part.

of sucrose than the shaded plants—particularly the first-order stalks which were the ones to suffer most from shading effects. The shaded plants have also a high percentage of glucose—not as an indication of greater vigor but probably of a slower rate of utilization. In this figure we see that the differences between shaded and exposed plants are not confined to one section only of the stalk, but throughout the whole length of the stalk. There are areas in these Islands subject to similar shading in the mornings. It is easy to see why these areas will not be equal either in tonnage or in quality to areas under continuous exposure.

X. Joint-to-Joint Analysis of Cane Stalks

We have seen in Fig. 20 that the sucrose per cent of juice is more or less uniform in the bottom, middle, and top sections of the dry-leaf part of the plant and that there is a sudden drop as we go from the dead-leaf to the green-leaf section. We are then interested in knowing whether the percentage of sucrose within the dry-leaf section is uniform throughout from joint to joint. We have made a large number of joint-to-joint analyses of stalks at different ages of which a few typical

examples are shown in the following Figs.: 23, 23-A, 23-B, and 23-C.* Let us first take a typical first-order stalk 26 months of age which has not tasseled (Fig. 23). The lowest joint has a Brix of 20°, and thereafter the Brix varies between 19° to 21° joint after joint until the fifty-fifth joint or so. In the succeeding top joints the Brix goes up to 23°, coming down again to 19° where the millable green-leaf part starts. From this point there is a sharp drop in Brix in successive joints until a reading of 11° is reached in the first non-millable joint of the stalk. We can simplify the picture by saying that all joints from the first to the seventy-fifth

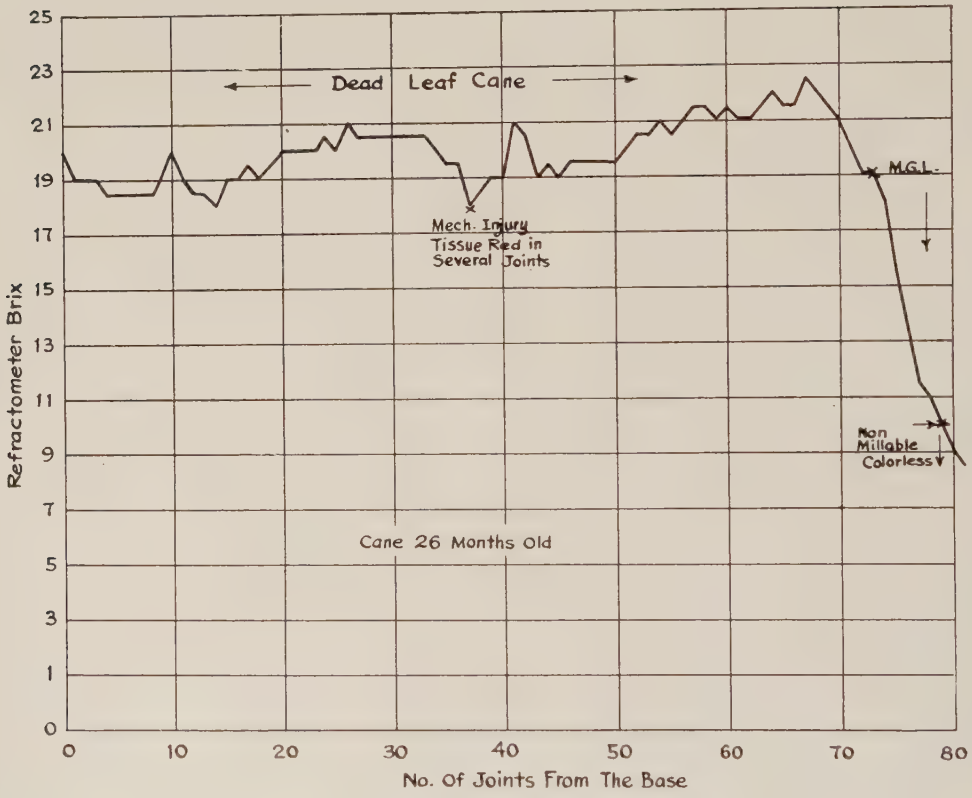
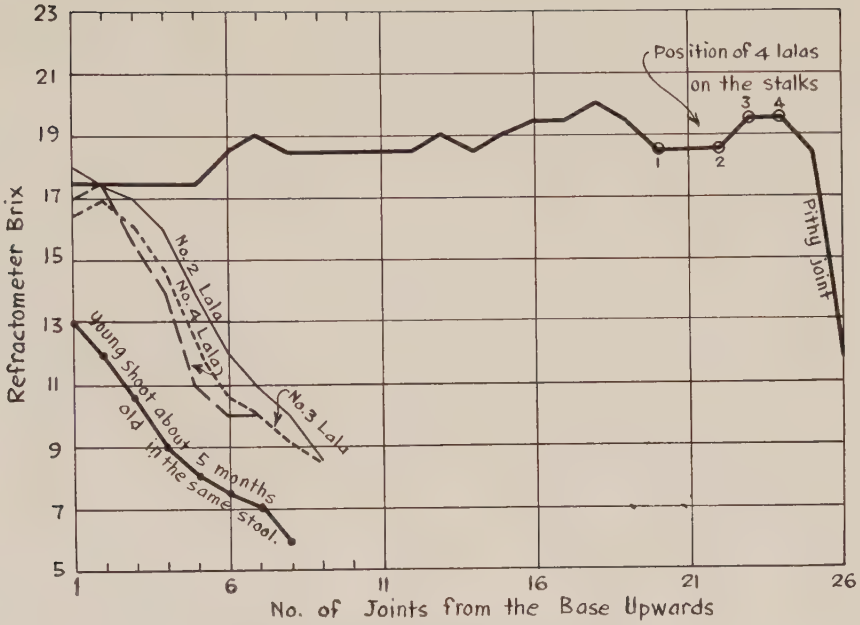


Fig. 23

In Figs. 23, 23-A, 23-B, 23-C, and 23-D the joint-to-joint analysis of Brix confirms our previous statement that the millable green-leaf part is the only part which is actively gathering sucrose. The level of Brix is more or less uniform from joint to joint throughout the entire length of the dry-leaf part. The level drops fast joint after joint as we reach the millable green-leaf part. It seems reasonable to assume that the dry-leaf part is more or less beyond improvement in the later stages of the crop. It is with the millable green-leaf part that we must be concerned in our effort to increase the average quality of juice. The ratio of the millable green-leaf to the dry-leaf part is thus an important factor in determining average juice quality of the whole stalk. The tasseled stalks, excepting the pithy joints, are uniform throughout in Brix.

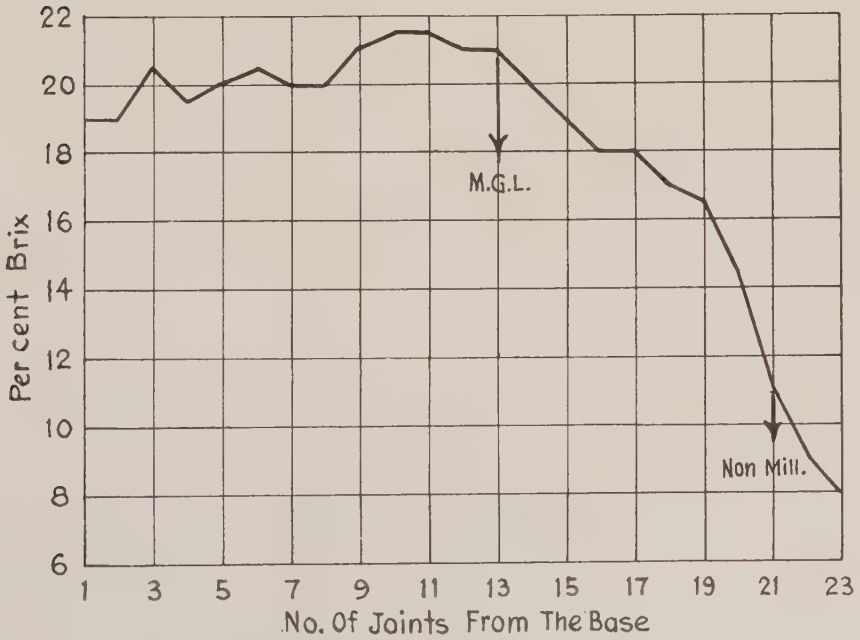
* In the joint-to-joint analyses, Brix readings were obtained for each joint, using a hand refractometer manufactured by Carl Zeiss, Inc.—the juice being extracted with a puncturing needle made by the same firm. This needle makes a clean puncture and extracts two or three large drops of juice at a time. The difference between duplicate readings from the same joint is seldom more than half a point. Needless to say the punctures should be made in the same relative position on each joint.



Sixth-order stalk—tasseled—with lalas.
Stalk—16 months old.
Lalas—about 4-5 months old.

Fig. 23-A

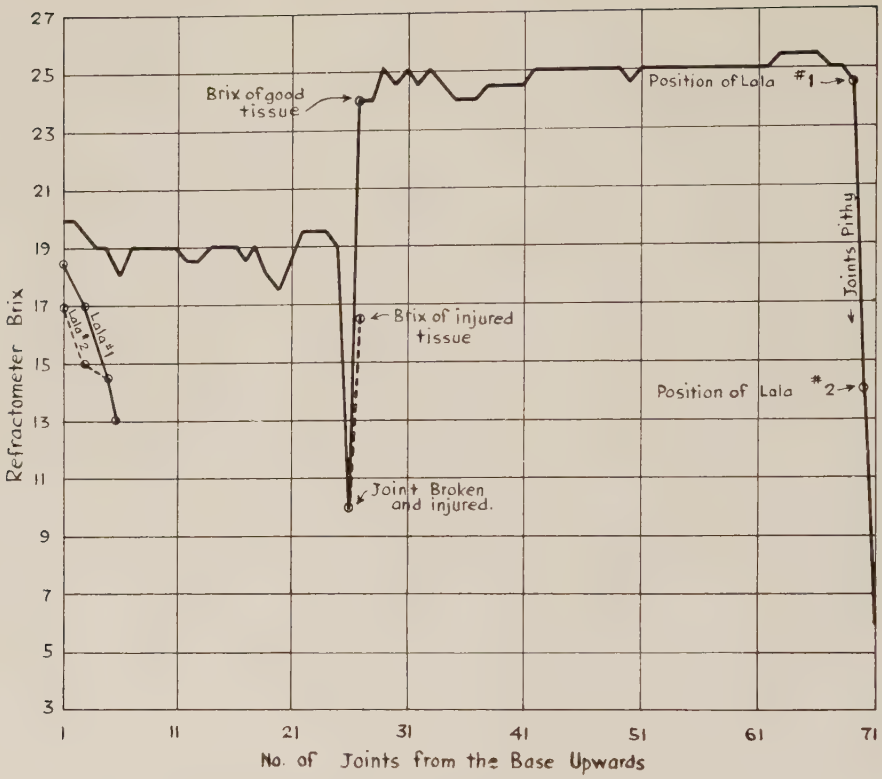
(For legend, see Fig. 23.)



Joint-to-joint analysis of refractometer Brix of a young sucker less than a year old.

Fig. 23-B

(For legend, see Fig. 23.)



Joint-to-joint Brix of a primary stalk 26 months old (Stalk tasseled 6 months before harvest).

Fig. 23-C

(For legend, see Fig. 23.)

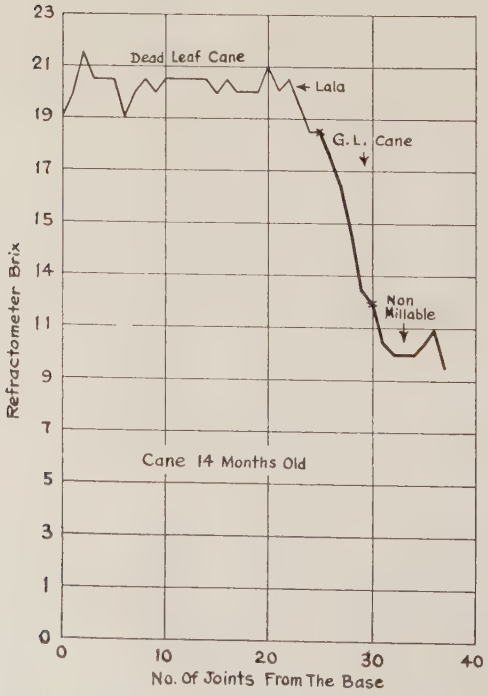


Fig. 23-D

(For legend, see Fig. 23.)

are on one level, the millable green-leaf on another and much lower level, and the non-millable on another still lower level. There is an abrupt change in the curve as soon as we come to the green-leaf part, as was so clearly brought out in the previous analyses of different sections of the stalk. We may therefore state that the entire dry-leaf part has reached about the same state of maturity while the green-leaf part is still immature and has yet to accumulate a great deal of sucrose.

Fig. 23 shows that the top joints just below the millable green-leaf part have the highest concentration of Brix. We have encountered this higher quality of the top joints previously in our sectional analysis of stalks and we find it now in our joint-to-joint analysis of big cane. We therefore feel that it is a significant fact to which attention must be drawn. Does the greater sucrose concentration in these top parts indicate that as the cane grows old, and vegetative vigor decreases, a relatively larger percentage of the sucrose elaborated is stored without being utilized in the formation of new matter? We would then picture the accumulation of sucrose joint by joint to be accomplished in the following manner: In the early stages of the crop there is a rapid expansion of vegetative growth. Each stalk is growing to an adult stage and also contributing to the support of others that are coming into existence. The expenditure of sucrose for building new tissue matter must be great at this time, relative to the assimilation of sucrose, and as a result we may expect less storage of unused sucrose. As the crop gets old and vegetative growth slows down, a large percentage of the sucrose elaborated may be stored, not being required for new growth. Therefore in the latter stages of the crop where growth is at a very low point due, among other causes, to the withholding of nitrogen, the sucrose storage in each joint must reach a very high level. In other words rate of utilization, rather than rate of formation of sucrose, governs its concentration in each joint. In the latter stages rate of formation may be low, but the rate of utilization may be relatively lower, with the result that net gain may be greater.

However, it must be borne in mind that as practical sugar planters we are not so much concerned with the rate of sucrose storage and its high concentration in the top joints, as we are with the total quantity of sugar (we should say total profit) that the stalk may yield. Rate of cane formation may then be the more dominant consideration. We shall discuss this point more fully in connection with our analysis of nitrogen fertilization.

We have definite evidence from a current experiment that the joint that is now elongating and is situated in the non-millable section goes through the green-leaf and reaches the dry-leaf stage in the short time of about 3 to 4 months. This means that the joints that now have practically no sugar will have reached a state of maturity with about 18° to 20° Brix in the course of the next 3 to 4 months. The accumulation of sucrose in the joints newly laid down must therefore be very rapid.

Let us next take the case of a sixth-order stalk harvested at the same time as the first-order stalk just discussed (Fig. 23-A). This sixth-order stalk was, however, only 15 to 16 months old at the time of harvest, having sprouted several months later than the first-order stalk. This stalk had tasseled so we have no green-leaf part, but here also the Brix level is practically uniform throughout the

entire length of the stalk. The Brix falls very rapidly as soon as we come to the terminal joints which are pithy as a result of tasseling.

Now take the case of a much younger stalk of cane—one that is less than 12 months old and has only 5½ pounds of millable cane and about 23 internodes (Fig. 23-B). Here again the entire dry-leaf section has about the same level of concentration, the Brix falling off rapidly as we come to the green-leaf section. It is thus stating a fact with no exaggeration to say that even a 6-month-old cane is more or less mature in the *dry-leaf part.*

Here is a unique case of a stalk that had been injured some time previously and was maintaining a growing and big top by the slender connection of the rind and a little tissue only (Fig. 23-C). This was a first-order tasseled stalk, 26 months old. The curve shows that in this stalk the lowest joint has a Brix of 20° and the figure remains between 19° and 20° for the next 20 joints; there is then a sharp decline in the course of one joint to a Brix of 10° (the tissue in the exposed part of the broken joint had deteriorated due to attacks of fungi and other organisms). In the very next joint the Brix rises to 24° and from then on a level of 24° to 25° Brix is maintained to the sixty-eighth joint, when the Brix falls to almost nothing in the course of another two joints. These last two joints were pithy as the after effect of tasseling. One is at once struck by the tremendous gradient of sucrose concentration that can exist in adjoining joints, and even in the adjoining tissues of the same joint; for in the joint (No. 27) next to the broken joint with 10° Brix we have the interesting fact that on one side of the internode where there is some red and deteriorated tissue the Brix is only 16°, while on the other side where the tissue is sound the Brix is 24°.

XI. Ripening or Maturity in Cane

No aspect of cane culture is more beset with confusion than ripening. What do we mean after all, by such terms as mature or ripe cane? In fruits or other crops there is no doubt what constitutes maturity, but in sugar cane there is unfortunately no such apparent and convenient index of ripeness. Maturity cannot simply be an arbitrary concentration of sucrose, for we realize that in different varieties and in different localities what are considered ripe canes will have widely differing sucrose contents. We also realize that occasionally heavy rainfall prior to harvesting a "dried-off" cane may dilute the juice of a so-called "ripe cane" and lower the concentration of sucrose without in any way lowering the total quantity of sugar in the stalk. Similarly an arbitrary percentage of glucose may not serve as an index of ripening. It has been suggested that purity or a simple sucrose-glucose ratio will provide a better index of maturity. It appears to us that no arbitrarily set constant will be satisfactory under all circumstances. Maturity would appear to be a relative term. We would like to define it as the accumulation by a variety of the maximum amount of sucrose under the conditions of culture and environment—in the process the green-leaf part of the stalk to gradually become smaller and smaller and be finally reduced to a negligible quantity. Ripening would thus be a process of lengthening the dry-leaf part and simultaneously shortening the green-leaf part. There is no doubt that this is about

all we do in our various efforts at "ripening-off," such as cutting off water, withholding nitrogen, etc.

Much of this confusion would be eliminated if we considered ripening as a continuous process and not as a last-minute effort of the plant which has grown vegetatively for 18 months and is building up sucrose in the stalk in the last few months before harvest. As each joint is laid, it accumulates sucrose, matures, and by the time it has reached the dry-leaf status it is already more or less mature. Once this conception of ripening, based as it is upon the facts of the situation, is realized by all of us who grow cane, we shall be less inclined to concentrate our efforts on ripening the cane in the last few months before harvesting, but so plan our agricultural policy that the cane will have ample opportunity to grow well and come to maturity in the natural course of events.

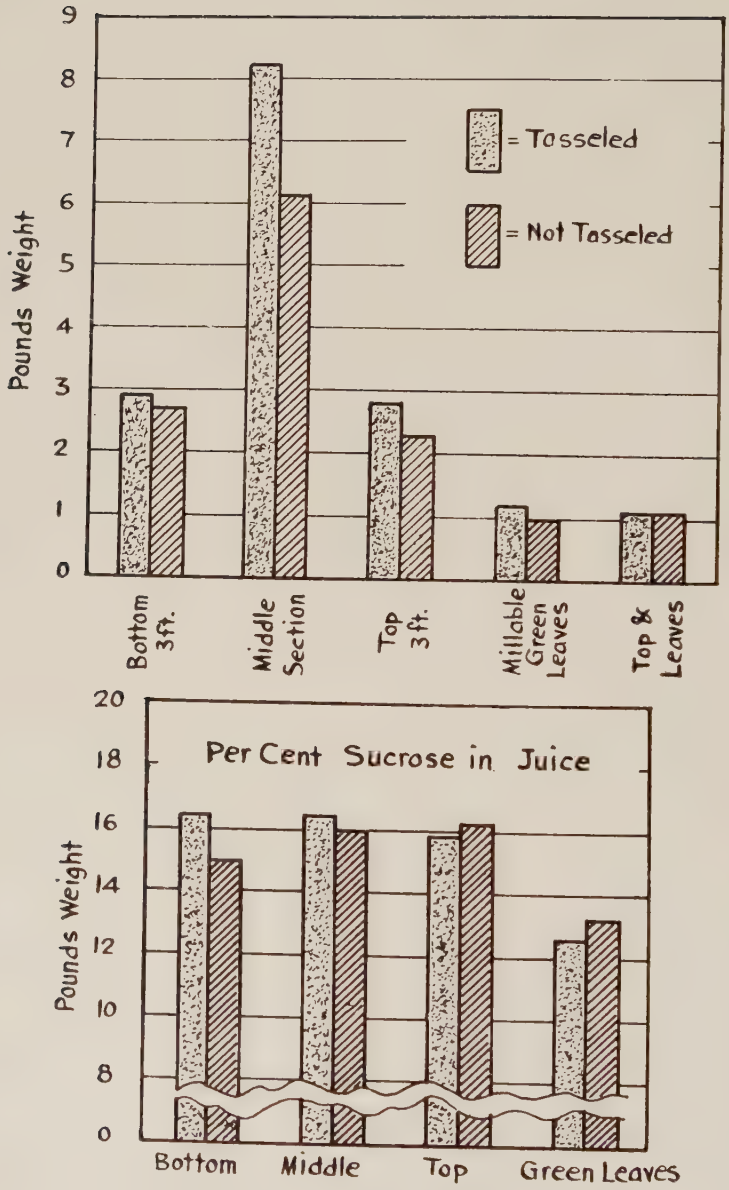
Our present studies clearly indicate that there is little possibility for the joint which has been laid 18 to 20 months ago to be still carrying on the process of sucrose accumulation. These joints may then be considered relatively fixed in sucrose per cent; the only joints on which we need concentrate our attention will be the millable green-leaf part. This being the case, could we not simplify our pre-harvest examination of a cane field by measuring the length or size of the green-leaf part of the millable stick instead of running detailed juice analysis of the whole stalk?

XII. Rate of Sucrose Accumulation at Various Ages

In a note appearing in *The Hawaiian Planters' Record,* Vol. XXXVII, p. 92, 1933, the writer showed that the rate of sucrose accumulation in a crop was highest between 9 and 12 months of age. Figs. 17 and 21 fully support our previous data. In both the March and September plantings, the rate is found to be highest between 9 and 12 months of age. This rate of sucrose accumulation is no doubt intimately related to the rate of cane formation at various ages and determined by the relative proportions of dry-leaf and green-leaf parts.

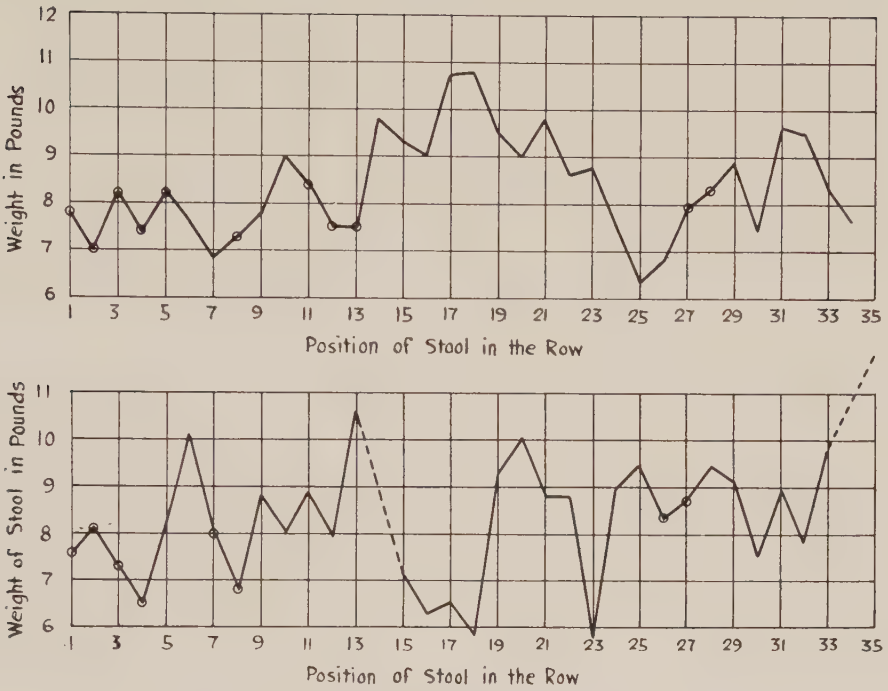
XIII. Tasseling Effect

A great deal of discussion still goes on as to the how and why of tassels, and controversy still rages as to their after effects. The data that we shall present do not answer the question why some canes tassel and others apparently very similar do not, but they do tell us what happens to the concentration of sucrose in the stalks after they have tasseled. In one line of March-planted cane, we segregated the second-order stalks according to whether or not they had tasseled. To further strengthen the comparison, we took only those stalks which were in the same stool, *i. e.,* growing from the same clump. These stalks which had been growing so intimately together may be believed to be as uniform as it is possible under field conditions; but when we analyzed the stalks we found that the tasseled stalks were on the average heavier than the untasseled stalks in the bottom, middle, top, and green-leaf sections (Table XIV and Fig. 24). With regard to sucrose, the tasseled stalks had a higher percentage in the bottom and middle sections, but slightly lower in the top and green-leaf sections (this lower concentration may



Comparing the weight and sucrose content of various parts of tasseled and untasseled stalks.

Fig. 24. The tasseled stalks are here seen to be heavier and richer in sucrose than the untasseled stalks from the same stool. This might suggest that it is only the more vigorous stalks that tassel, but quite a different picture is given by Fig. 25.



Showing the weight of successive first-order stalks in two rows of cane. (September planting.)

Fig. 25. The weights of successive first-order stalks in two lines of cane are shown. Those that tasseled are marked by circles. Tasseling does not seem to be confined either to the most- or to the least-vigorous stalks but to stalks of about average weight.

indicate that some sucrose was used by the tassel). If this evidence stood alone we might have concluded that generally the stalks that were more vigorous were the ones that tasseled, but quite a different picture is presented by the cane in the September planting. Fig. 25 shows the weight of the first-order stalks of two lines of cane and their respective positions in the row. The figure also shows which of these stalks tasseled and which did not. We observe immediately that tasseling is scattered here and there in apparent confusion. Tasseled stalks seem to be more concentrated toward one end of the row than the other. The end having more tassels happens to be the exposed end, that is, there was no cane beyond this end, but the point we started to make is that tasseling seems to be confined not to the most vigorous stalks, nor to the very weak stalks, but to stalks that are of average weight. In other words the more vigorous stalks do not necessarily tassel. Thus tasseling still remains a mystery. The fact that neither the extremely weak nor the extremely vigorous stalks tassel may lead us to the assumption that tasseling may be conditioned by a balance of factors within the plant—factors of which we know nothing for certain.

Effect on juices: The joint-to-joint analysis of tasseled stalks produced previously (Figs. 23-A and 23-C) shows that there is no evidence of the tasseling stalks going back in juice quality so long as the top has not started to die and degenerate. If we eliminate the one or two joints with pithy tissue, then we shall

find a tasseled stalk to be remarkably uniform in sucrose throughout its entire length. Furthermore, in such a stalk with no green-leaf part, the average sucrose concentration should be higher than an untasseled stalk which has a green-leaf part. However, it goes without saying that if we had a large number of pithy joints included in the stalk we should have an entirely different picture, for the pithy joints appear from our data to have very little sucrose.

We must realize, however, that an untasseled stalk which kept on growing may have more total sugar than a tasseled stalk, because of greater weight of cane.

XIV. Lalas

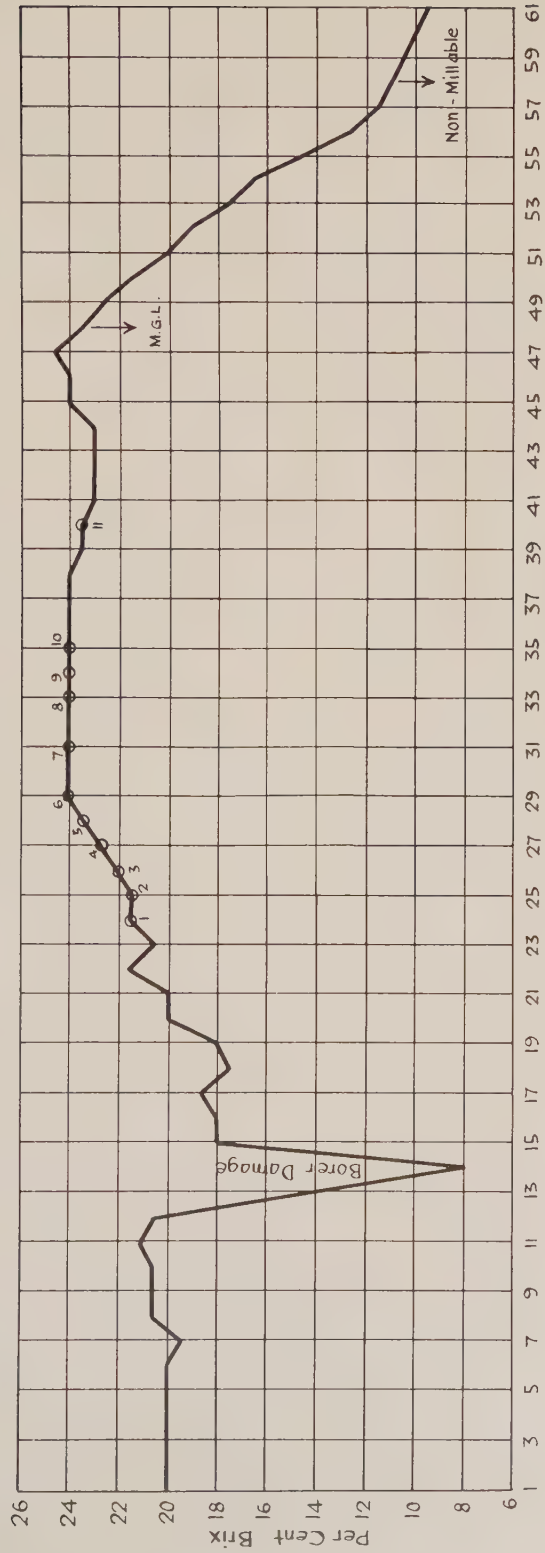
Lalas are side shoots that germinate from a dormant eye on a growing cane. The lalas draw nutrition only through the mother stalk and are not rooted in the soil like late suckers.

The lalas are generally considered to be an evil even though a necessary one. It is generally believed that lalas withdraw sucrose from the parent stalk while they themselves do not add much to the crop. Our data clearly show that not only are lalas not harmful (under the conditions of the experiment at least) but they have also more sugar than the suckers of equal age. Previously (Fig. 20) we have seen that even the small lalas that would not generally be harvested in the field had a sucrose concentration more approaching the parent stalk on which they were growing than the suckers with which the lalas were comparable in age. Fig. 23-A shows a joint-to-joint analysis of some lalas growing on a sixth-order stalk and also an analysis of a young sucker growing in the soil in the same stool. The lalas are on a much higher level than the sucker, but the Brix curves of both are of similar nature. Fig. 26 shows another extreme case of lala-ing in a big cane. This stalk had in all 11 lalas coming out at the internodes marked, but we fail to see any evidence of the deterioration of juices in any of these joints. If anything, the joints bearing the lalas had the highest sucrose content.

Fig. 27 shows the joint-to-joint analysis of that part of the mother stalk where the lalas were growing and the analysis of 4 millable lalas. There is very little evidence to say that the mother stalk had suffered appreciably from supporting these millable lalas. The analysis of the lalas proves of extreme interest. The nature of the Brix curve is the same as we have met before in suckers, but the level of concentration is very high for cane of such age and vigor. Even in the green-leaf parts the Brix is as high as 20°. Is this merely a result of the then growing conditions or does this high level suggest that the lalas have a greater capacity for sucrose accumulation because they are deriving some benefit from their intimate association with the big canes? Note again the great variation in the 4 lalas growing from adjacent joints of one cane.

XV. Influence of Borer and Mechanical Injury on Quality

The joint-to-joint analysis of stalks, that has been presented previously shows how badly the quality of a joint can be affected by borers or mechanical injury. In Fig. 23-C the Brix drops from 20° to 8° in going from one joint to another (in another extreme case, not reported in this paper, the Brix dropped to 2° in joints injured by borers). In other words one such poor joint pulls down the average



Joint-to-joint analysis of a first-season cane which had sent out a large number of lalas. The lalas are numbered and their position indicated.

Fig. 26. This first-season cane had 11 lalas on it when harvested. The qualities of the joints to which the lalas were attached are shown. There does not appear to be any deterioration of juices in the joints carrying the lalas. On the contrary these joints are the highest in Brix.

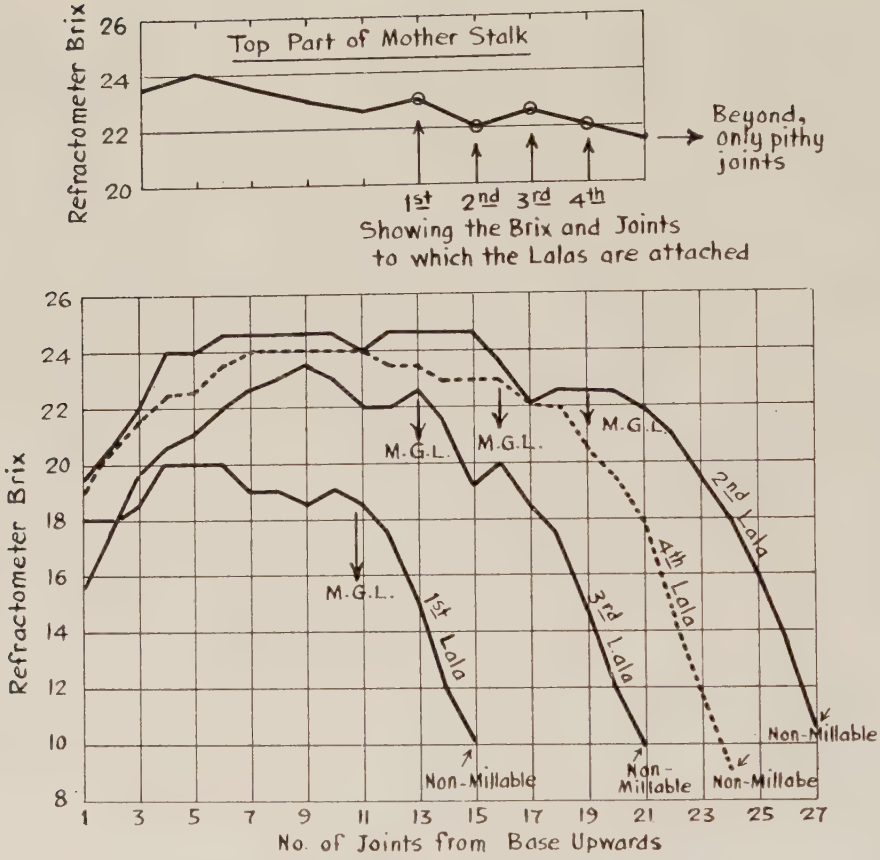


Fig. 27. Showing the joint-to-joint quality of four lalas growing from adjacent nodes of a first-season cane. These millable lalas growing from adjacent joints of a single stalk show remarkable variations in Brix content. The curve of Brix concentration from joint to joint is, however, of the same nature as shown previously with suckers. Note the high values obtained in the green-leaf parts.

for 12 or more joints by one whole point of sucrose on the basis of equal weight of juice. If we had 2 or 3 such joints in a cane, we might expect the average Brix for a whole big stalk to be lowered by one point.

XVI. Second-Season Application of Nitrogen

In the last few years there has been a marked tendency on the part of the industry to apply the last application of nitrogen at least 10 to 12 months prior to harvesting. In extreme cases this interval between the last application of nitrogen and harvest has been even greater. It has been argued that by so doing we are likely to get better juices. It is not our purpose to criticize this trend. All of us know that this policy has been an improvement on the past, but we want to raise the question whether or not the time has not come to re-examine the whole subject. In striving for quality are we sacrificing cane tonnage and sugar? Is it not possible to combine the advantages of quality and quantity by a different procedure?

These questions are being raised as a result of observations and some evidence tending to show that by stopping nitrogen applications so early in the life of the

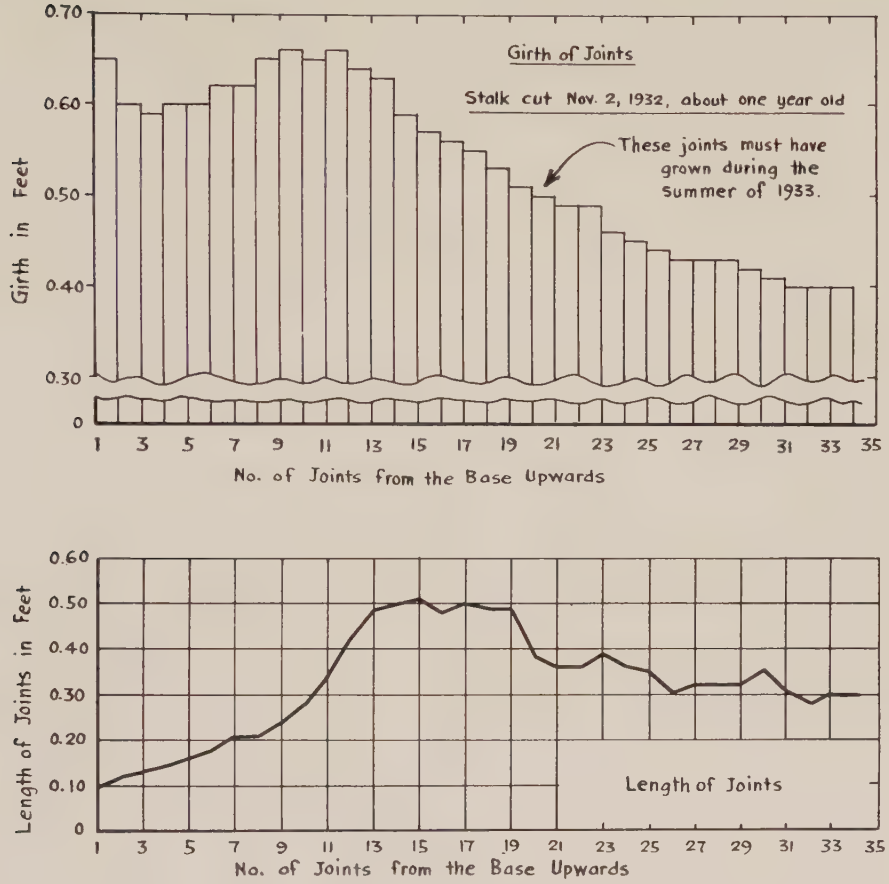

Girth of Joints
Stalk cut Nov. 2, 1932, about one year old
These joints must have grown during the summer of 1933.
Girth in Feet
0.70
0.60
0.50
0.40
0.30
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
No. of Joints from the Base Upwards
Length of Joints in Feet
0.60
0.50
0.40
0.30
0.20
0.10
0
Length of Joints
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
No. of Joints from the Base Upwards

Fig. 28. The girth and length of each successive joint of a second-season stalk (sixth order) are here shown. The decrease in length and girth during the summer months is believed to be due to deficiency of plant food, particularly nitrogen.

crop we are not only starving the big cane, and increasing its chances of deterioration, but we are also depriving the second-season cane of much needed nourishment. We have remarked when discussing the rapid mortality after tasseling of the March-planted cane, that lack of vigor induced by lack of nitrogen might have been the contributory cause. Some measurements taken on second-season suckers appear to indicate the same lack of vigor and nitrogen deficiency. When these suckers came out, the joints were long and thick, but soon afterwards the joints started to shorten and grow less in girth, the tops became smaller, even though the stalks were going through the summer months. Fig. 28 will show the girth and length of each successive joint of a second-season stalk. From the time this one sprouted there had been applied only one application of nitrogen, the last one called for in our plan. Analysis of total nitrogen in second-season and first-season stalks (Table XV, Fig. 29) shows that the second-season stalks had actually much less nitrogen than the first-season cane. Thus the second-season canes which at times numbered about 20 per cent of the total stalks harvested were left without nourishment; whereas, with more timely fertilization these might have contributed more substantially toward the total crop. It is interesting to speculate on what might

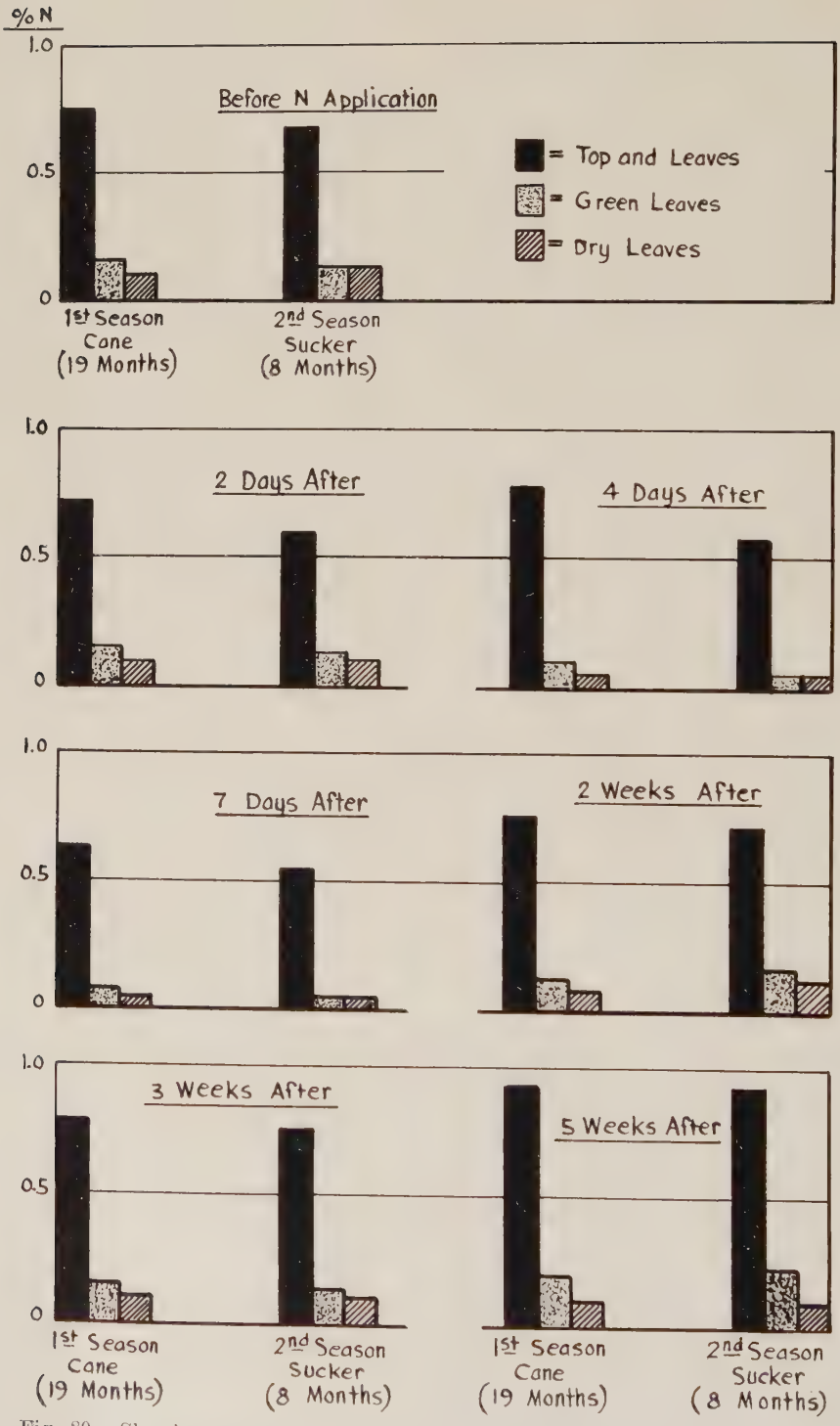


Fig. 29. Showing percentage of total nitrogen on dry basis in the different parts of first- and second-season cane. The young second-season suckers are seen to have less nitrogen in their composition than the old first-season cane. It is suggested that this difference is due to the fact that very little nitrogen was applied since the second-season cane had come into existence. After an extra application of nitrogen, the suckers caught up with the others in nitrogen in about four weeks' time.

have happened to these fields both to the first- and the second-season cane had we applied another and a later application of nitrogen. Could we not have saved mortality in big cane and stagnation in the young?

After these symptoms of nitrogen starvation had become quite pronounced and we had discovered that the second-season cane, which because of its age should be in greater vigor, had actually less nitrogen, we attempted to correct these conditions by applying an extra amount of 50 pounds of nitrogen per acre. The nitrogen analysis of the series following this application proves to be an interesting study. About three weeks after application we found that the second-season suckers were catching up with the first-season cane in per cent nitrogen, and in the fifth week the two groups were identical. The data also indicate that the relative uptake of nitrogen was greater in the case of the second-season cane—which was poorer to start with than the first-season cane.

We would strongly suggest that this aspect of our fertilization policy receive more careful study. We are of the opinion that particularly under irrigated conditions it may be profitable to apply nitrogen later in the season. Should the quality go down somewhat, we may still make more sugar due to a bigger tonnage of cane.*

It may be regrettable to some that a study undertaken in response to an urge on the part of the industry to improve upon the quality of cane offers as one of its first practical suggestions the thought that we might with advantage have recourse first to higher tonnages under somewhat poorer juice quality. But such is the deduction to which the analysis of our data leads us.

XVII. Day-Degree and Cane Yield

We have made a study of the relation of day-degree to cane yield at various ages. Fig. 30 shows that there is a general agreement between the total day-degrees and yield of cane up to about 22 months, or up to the time the field as a whole has not started to deteriorate. It is also of interest to note that the average gain in weight of the first-order stalks of March-planted cane between September, 1931 and August, 1933, was practically the same as the gain in weight of September-planted cane between the same two dates. Naturally the total day-degrees were the same in both cases.

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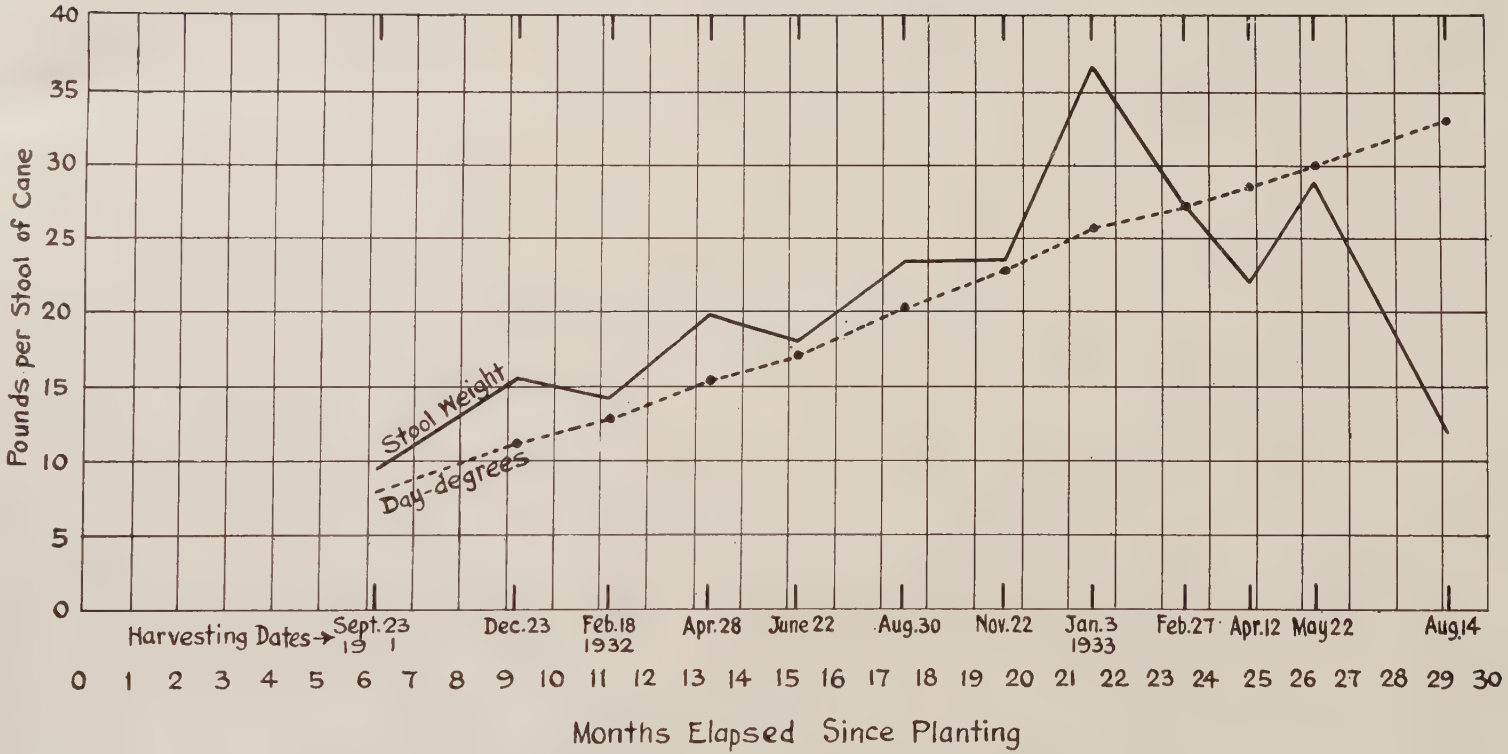
* To further elucidate our point let us take two types of stalks—one type having a large vigorously growing top and the other a very small, fan-shaped top indicating cessation or near cessation of growth. Let us further suppose that the vigorous type results from our more generous application of plant food and the short top from cutting down the nourishment. The big-top cane has a lower level of sucrose concentration and the short-top one a much higher level. If we were merely looking for quality we would certainly want the short-top type, but if we were more interested in total amount of sugar we might have chosen the big-top type. Here are some data in qualitative support of the above: We cut two stalks of the types as here suggested. The stalks were of about equal age and growing close together. The juice analysis showed the Brix of the dry-leaf part to be as follows: Big top 18.62°, small top 21.41°, and of the green-leaf part 14.53° and 15.23° respectively. But the weights of the green-leaf part in the two cases were 2.94 and 0.25 pounds respectively, and the dry-leaf parts 8.5 and 8.1 respectively. First of all, multiplying the weight of cane by the Brix we find the current production of total sugar (*i.e.* sugar in the green-leaf part) to be very much higher in the big top with a smaller Brix concentration than in the small top with a larger concentration. Secondly that the total sugar in the whole big stalk is greater than in the one with a small top.



Relation of average weight of a stool of cane at different dates to accumulated day-degrees.

Fig. 30. The agreement between day-degree and cane-yield was generally good until the field started to deteriorate after tasseling.

XVIII. Soil Temperature

Whenever the relation of temperature to cane growth is discussed someone is sure to enquire about the relation of soil temperature to some aspects of growth. At the start of this experiment we installed a thermograph to record temperature at one foot below the ground, with the purpose of utilizing the data in our study. A continuous record is available for the past years, but so far we have been unable to correlate the data with either the yield or the quality of cane.* There are, however, some points of interest about the data which we would like to bring out.

Study of some of the records reproduced (Figs. 31, 31-A) will show daily fluctuation in temperature when the cane was young and the soil exposed to the sun. As the cane started to close in, the weekly graph started to straighten out and from the first 5 or 6 months after planting to the last harvest at 30 months the graph remained almost a straight line from day to day. There were, however, variations from week to week and month to month. The difference between mean maximum air temperature and the soil temperature was only about 8° at the start of the experiment, this difference gradually increasing to 16° F. in the second year. Due to the effect of trash blanket and growing cane the soil temperature of the summer months of 1932 is much lower than the same months of 1931 while the air temperature is a little higher in 1932 than in 1931.

Another point of interest brought out by the thermograph data was that every Monday and Thursday at about eight in the morning the soil temperature went down a degree or two in the summer months and went up a degree or two in the winter months. Those were the days and the hours when we irrigated our cane. Evidently in the summer months the irrigation water was cooler than the soil and in the winter months the reverse. The graphs also show that it usually took about 48 hours for the soil temperature to come back to the normal weekly level.

Undoubtedly in areas using very cold mountain water the cooling effect will be even greater. If soil temperatures do govern growth processes to any marked extent, then this lowering of soil temperature may be of considerable practical interest in certain areas. Particularly is this true when we are putting on needless irrigations during the winter months.

XIX. Summary

This paper is a study of the composition of a cane crop and its influence on cane yield and juice quality. In this study it is shown that a cane crop, at any time, consists of stalks of different ages and consequently in different stages of vigor and maturity. The average yield and quality, being a composite of these different kinds of stalks, are naturally influenced by the relative proportion of these stalks at different ages.

Suckering: Suckering is found to be a continuous phenomenon in a field of cane. It is primarily influenced by self-shading due to plant competition. In-

* All through the literature, we find references to the dominant influence of soil temperature on the germination of seeds, on the microbiological activity and the CO_2 formation in the soil. We feel sure that the soil temperature must affect all the physical and chemical processes that are initiated in the root. Here at the Experiment Station we supply bottom heat to the young cane seedlings to obtain better growth, but we confess that we do not know of any experimental data which show the extent to which aerial growth of adult plants is affected by small variations in soil temperature.

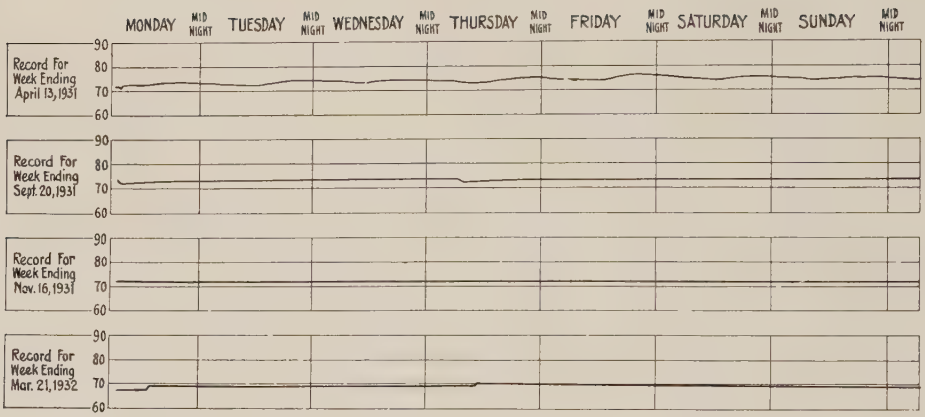


Fig. 31. Some typical weekly charts are here reproduced to show how the fluctuations in soil temperature are governed not only by the stand of cane but also by the temperature of the irrigation water in different seasons of the year.

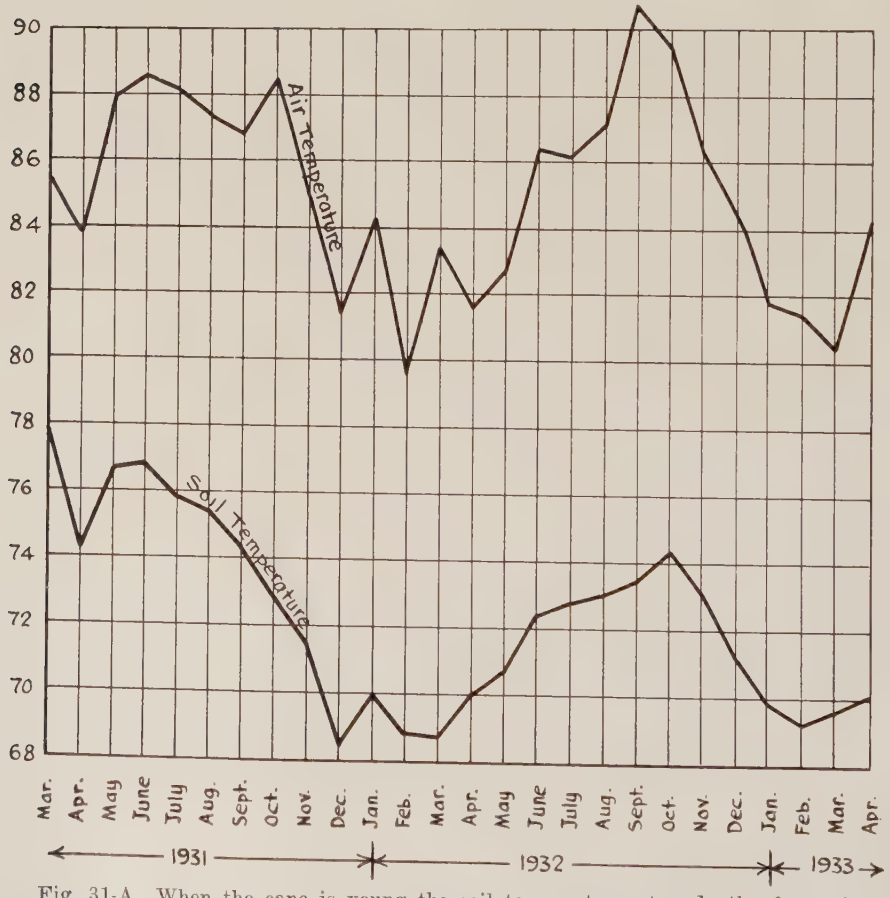


Fig. 31-A. When the cane is young the soil temperature at a depth of one foot is only about 8° below the mean maximum air temperature. The difference increases as the cane closes in. In the second year the difference increased from 8° to about 16°. Although the air temperatures of 1931 and 1932 are alike, the soil temperature of the summer of 1932 (under big cane) is much lower than that of the summer of 1931 (small cane). We do not know as yet if this difference is of significance to cane growth.

dependently of the season the number of suckers reaches a maximum between 4 and 5 months of age or just when the crop closes in. This maximum is followed by a decline to a more or less stable number of about 3 stalks per foot for H 109 cane.

Millable cane: A crop of H 109 under the experimental conditions consists very largely, 80 to 100 per cent, of stalks that germinate within 3 months after planting.

In our experiment, March-planted cane appears to be more suited to a long crop, and September-planted cane to a short crop. The extent of tasseling and its relation to the application of fertilizers appear to be considerations of utmost importance for determining the proper crop length.

Sucrose: Excellent juices have been obtained from both the first- and second-season cane in spite of a continuous application of 4 inches of irrigation a week to the very day of harvest. There was no indication of deterioration of juice with age in those stalks that remained sound; for the per cent of sucrose in all orders of stalks continued to improve to 29 months after planting, and both the second-season suckers and the lalas proved to be as good and at times better than the first-season cane in sucrose.

Sucrose in different parts of the same stalk: It has been very definitely brought out that the millable cane may be divided, from the viewpoint of quality, into two sections: (1) the dry-leaf cane, (2) the green-leaf cane (the green-leaf cane is defined as that part of the millable stalk where green leaves are still attached). At any stage in the development of the plant the dry-leaf section appears to be more or less mature. It is in the green-leaf section where active accumulation of sucrose is still going on. The dry-leaf section may then be considered as beyond the reach of ordinary cultural treatments.

The average juice of the whole stalk is a composite of the dry-leaf and the green-leaf sections and as such must be greatly influenced by the relative proportion, of juice by weight, of these two sections. The difference in the average quality of an old cane and a young cane may then be due primarily to the difference in the ratios of these two parts. It is suggested that maturity may more logically be considered as the shortening of the minimum of the green-leaf section, than as an arbitrary concentration of sucrose or glucose in the stalks.

Joint-to-joint analysis of stalks strengthens the points just brought out.

Second-season fertilization: The results suggest a re-examination of our second-season fertilization policy to see whether or not we have gone beyond the limits of best practice in avoiding fertilization of cane late in the crop.

Many other points of importance to a full understanding of the cane crop are also discussed; such as the extent of variations from stalk to stalk and within different parts of the same stalk, the effects of tasseling, shading, soil temperatures, etc.

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TABLE I

Relation of the number of shoots per stool at the age of ten weeks and the length of the primary stalk

Number of shoots per stool	Number of stools having the stated number of shoots	Average length of first-order stalks in the stools
6	3	14.7 inches
5	32	12.8 "
5	79	12.2 "
3	75	11.7 "
2	50	10.7 "
1	24	10.0 "
0	52	8.6 "

Total 315 stools or 9 lines of cane

TABLE II

Total Number of Shoots at Various Dates—Cane Planted March 17, 1931—Average of Sections A, B, C and F

Date	11/4/32	6/2/31	6/30/31	8/2/31	10/7/31	12/12/31	2/7/32	4/3/32	6/4/32	8/26/32
Average of outside lines	35	138	190	249	125	151	150	172	194	146
Average of first inside lines	35	122	173	197	98	100	91	96	123	106
Average of second inside lines	35	133	185	205	110	98	93	97	122	103
Approximate number of months since planting	1	2½	3½	4½	7	9	11	13½	15½	18

September Planting—Section H Only

Date	10/17/31	12/31/31	2/7/32	4/5/32	6/4/32	9/7/32
Outside lines*	35	179	233	207	131	96
First inside line	35	144	181	163	108	99
Second inside line	35	134	179	158	96	87
Approximate number of months since planting	1	3½	4½	7	9	12

* It has been explained in the body of the report that this was an outside line for a short time only. As the cane in the adjoining section got big this outside line ceased to be an outside line in the true sense.

TABLE III

No. of Shoots on	Oct. 17, 1931	Dec. 11, 1931	Increase or Decrease
Section A—Line 1 (outside)	124	145	+21
2 (inside)	102	98	— 4
3 (inside)	97	99	+ 2
Section B—Line 1 (outside)	114	155	+41
2 (inside)	91	106	+15
3 (inside)	114	106	— 8
Section C—Line 1 (outside)	127	166	+39
2 (inside)	99	99	0
3 (inside)	109	93	—16
Section F—Line 1	135	138	+ 3
2	98	96	— 2
3	118	93	—25

TABLE IV

Weight of millable cane and green top per line for different orders of stalks—March planting

Date of harvest	Approximate age in mos.	First-order. Pounds of		Second-order. Pounds of		Total weight in pounds of first, second and other orders	
		Millable cane	Green top	Millable cane	Green top	Millable cane	Green top
September 23, 1931	6¼	107.30	....	210.28	.....	317.58	.....
Dec. 23, 1931	9¼	188.25	....	377.75	.....	583.88	.....
February 17, 1932	11	184.95	....	317.69	.....	506.27	.....
April 28, 1932	13½	232.06	64.38	460.56	147.60	693.50	242.60
June 22, 1932	15¼	252.13	51.63	377.13	87.63	635.26	153.00
August 30, 1932	17½	261.38	42.70	539.38	97.50	820.01	154.20
November 2, 1932	19½	277.46	29.94	513.24	64.73	828.50	102.60
January 3, 1933	21½	358.09	25.74	775.03	62.53	1290.75	118.23
February 27, 1933	23½	247.16	17.89	600.49	29.47	943.66	66.38
April 12, 1933	24¾	232.79	16.27	429.90	31.02	770.47	70.53
May 22, 1933	26¼	125.44	10.32	704.83	45.85	1023.41	83.02
August 14, 1933	29	77.75	10.01	276.71	32.64	450.04	65.85

TABLE V

Number of stalks harvested per line at different ages
March-planted cane

Date of harvest	Approximate age of field in months	Number of first-order stalks		Number of second-order stalks	Total number of stalks in the line
		Total	Stalks with healthy tops only		
December 23, 1931.....	9¼	35	35	88	123
February 17, 1932.....	11	35	35	70	107
April 28, 1932.....	13½	35	35	78	113
June 22, 1932.....	15¼	35	29	60	96
August 30, 1932.....	17½	33	25	63	105
November 2, 1932.....	19½	34	17	54	92
January 3, 1933.....	21½	33	26	66	120
February 27, 1933.....	23½	26	10	53	91
April 12, 1933.....	24¾	21	12	36	71
May 22, 1933.....	26¼	10	8	51	75
August 14, 1933.....	29	6	4	26	42

TABLE VI

Average weight of millable cane and green top of first-order stalks at different ages

Date of harvest	Approximate age in months	Millable cane in pounds		Green weight in pounds
		All stalks	Stalks with healthy tops only	
September 23, 1931.....	6¼	3.07	....	....
December 23, 1931.....	9¼	5.21	....	....
February 17, 1932.....	11	5.28	....	....
April 28, 1932.....	13½	6.63	....	1.84
June 22, 1932.....	15¼	7.31	8.20	1.50
August 30, 1932.....	17½	8.03	9.24	1.31
November 2, 1932.....	19½	8.30	11.34	0.90
January 3, 1933.....	21½	10.86	12.14	0.78
February 27, 1933.....	23½	9.50	13.32	0.69
April 12, 1933.....	24¾	11.09	15.23	0.78
May 22, 1933.....	26¼	12.54	13.55	1.03
August 14, 1933.....	29	12.96	16.94	1.67

TABLE VII

Total weight in pounds of millable cane and green top of different orders harvested at different ages—September-planted cane

Harvesting date	Approximate age in months	First-order		Second-order		All orders—First, second and others	
		Millable cane	Green top	Millable cane	Green top	Millable cane	Green top
July 1, 1932.....	9½	160.0	64.75	175.50	84.75	372.0	176.12
September 8, 1932.....	11¾	220.0	55.15	519.0	141.10	754.81	200.69
November 14, 1932....	14	289.95	61.05	476.10	111.48	777.55	176.16
February 6, 1933.....	16½	275.97	51.98	487.14	86.77	744.11	138.75
March 29, 1933.....	18½	255.99	39.42	472.93	86.23	728.92	129.90
May 15, 1933.....	20	266.53	37.42	466.56	68.66	735.22	113.33
August 15, 1933.....	23	313.48	32.35	478.66	51.51	868.24	178.73
October 17, 1933.....	25	309.98	31.49	457.35	47.39	840.86	110.39

TABLE VIII

Number of stalks harvested per line at different ages—September-planted cane

Harvesting date	Approximate age in months	First-order stalks	Second-order stalks	All orders of stalks
July 1, 1932	9½	35	55	115
September 8, 1932	11¾	35	83	121
November 14, 1932	14	35	65	103
February 6, 1933	16½	34	59	93
March 29, 1933	18½	29	55	85
May 15, 1933	20	33	59	93
August 15, 1933	23	31	52	90
October 17, 1933	25	30	44	79

TABLE IX

Average weight of millable cane and green top* of first- and second-order stalks September-planted cane

Harvesting date	Approximate age in months	First-order		Second-order	
		Millable cane	Green top	Millable cane	Green top
July 1, 1932	9½	4.83	1.85	3.19	1.54
September 8, 1932	11¾	6.29	1.60	6.25	1.70
November 14, 1932	14	8.28	1.74	7.32	1.72
February 6, 1933	16½	8.12	1.53	8.26	1.47
March 29, 1933	18½	8.83	1.36	8.60	1.57
May 15, 1933	20	8.08	1.13	7.91	1.16
August 15, 1933	23	10.11	1.43	9.21	1.68
October 17, 1933	25	10.33	1.05	10.39	1.08

* Includes the green weight of lalas growing on first- and second-order stalks.

TABLE X

Average weight of millable cane per running foot of row in the shaded and exposed sections of the same line of cane

Date of harvest	Age of the crop in months	Pounds millable cane per foot	
		Shaded section	Exposed section
July 1, 1932	10	9.00	10.56
September 8, 1932	11¾	11.62	13.21
November 14, 1932	14	11.83	20.68
February 4, 1933	16½	20.39	19.26
March 29, 1933	18½	14.20	19.10
May 15, 1933	20	11.71	21.64
July 10, 1933	22	18.95	21.17

TABLE XI

Harvesting date	Age of field in months	First-order		Second-order		Third-order		Fifth-order		Sixth-order		Seventh-order		Eighth-order		Higher order	
		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Sept. 23, 1931....	6¼	7.63	...	5.62	...	...	...	...	...	...	...	...	...	...	...	...	...
Dec. 23, 1931.....	9¼	9.75	2.04	8.14	2.32	6.30	2.54	...	...	...	...	...	...	...	...	...	...
Feb. 18, 1932.....	10¾	12.65	1.33	12.83	1.21	9.72	1.38	...	...	...	...	...	...	...	...	...	...
Apr. 28, 1932.....	13½	13.72	.97	14.13	.78	...	...	...	...	...	...	...	...	...	...	...	...
June 22, 1932.....	15¼	15.09	1.02	15.69	.86	...	...	...	...	...	...	...	...	...	...	...	...
Aug. 30, 1932.....	17½	15.29	1.01	15.37	.64	...	...	...	...	...	...	8.92	1.72	...	...	...	...
Nov. 2, 1932.....	19½	14.42	.91	15.05	.89	16.55	.59	14.89	.89	13.78	1.17	12.26	1.40	...	...	...	...
Jan. 4, 1933.....	21½	15.25	.90	15.55	.67	...	...	...	...	16.29	.50	15.01	0.81	...	...	...	...
Feb. 28, 1933.....	23¼	13.67	1.03	14.02	.87	13.95	.93	14.89	.63	16.89	.25	16.31	0.37	13.74	0.56	...	...
Mar. 16, 1933.....	24	16.51	.57	16.10	.56	...	...	...	...	16.14	.39	13.55	0.56	...	...	...	...
Apr. 13, 1933.....	25	16.69	.50	16.48	.53	17.61	.27	...	...	19.09	.09	17.99	0.23	...	...	...	...
May 23, 1933.....	26¼	17.93	.42	16.61	.49	16.40	.60	17.43	.59	18.80	.22	17.85	0.27	...	...	...	...
Aug. 15, 1933.....	28	18.04	.40	17.54	.56	18.98	.21	20.93	.33	17.67	.33	15.28	0.71	14.36	0.81	13.08	1.07

TABLE XII

Percentage of sucrose and glucose in different sections of the stalks

(A) Harvested Sept. 8, 1932—Outside line—Age about 18 months

	First-order		Second-order		Fifth-order		Sixth-order		Seventh-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4'	18.51	0.66	18.97	0.33	....	...	....	...	...	....
Middle	18.34	0.34	18.77	0.20	15.52	0.50	....	...	...	....
Top 4'	17.52	0.44	17.23	0.80	15.19	0.87	14.30	0.99	0.86	14.22
Millable green-leaf	12.85	1.88	12.52	1.96	12.18	1.54	9.98	1.70	1.58	9.58

Lalas (composite of whole stalk)
Sucrose=16.38%
Glucose= 0.80%

(B) Harvested Dec. 20, 1932—Inside line—Age about 21 months

	First-order		Tasseled		Untasseled		Sixth-order		Seventh-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4'	15.33	0.46	15.78	0.56	13.41	0.87	15.39	0.35	....	...
Middle	16.45	0.44	16.34	0.50	14.23	0.78	14.91	0.66	13.35	1.18
Top 4'	15.62	1.03	15.15	1.14	14.92	1.14	15.10	0.80	13.64	1.11
Millable green-leaf	12.35	1.67	12.36	1.65	12.75	1.70	12.30	1.57	9.42	1.77

(C) Harvested April 11, 1933—Inside line—Age about 25 months

	First-order		Second-order		Third-order		Fifth-order		Sixth-order		Seventh-order		Eighth-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4'	15.69	0.45	15.62	0.42	16.67	0.24	17.89	0.13	18.35	0.17	....	...	....	...
Middle	17.71	0.38	16.56	0.52	15.76	0.54	18.93	...	18.28	0.37	17.06	0.36	....	...
Top 4'	18.94	0.21	17.18	0.45	17.73	0.30	19.13	...	18.67	0.14	18.05	0.19	14.44	0.63
Millable green-leaf	13.61	...	13.61	0.77	....	...	....	...	....	...	....	...	....	...

Lala on first- and second-orders (whole stalks)
Sucrose=14.72%

TABLE XIII

Percentage of sucrose and glucose in September-planted cane at different ages

Harvesting date	Field age in months	First-order			Second-order			Third-order		
		Sucrose	Glucose	Q. R.	Sucrose	Glucose	Q. R.	Sucrose	Glucose	Q. R.
July 1, 1932	9½	11.38	2.12	13.45	9.43	2.59	17.90	5.97	3.06	34.99
September 9, 1932	11¾	15.74	2.46	8.68	15.07	1.34	9.31	12.94	1.62	11.51
November 15, 1932	14	14.97	0.99	9.04	14.91	1.02	9.22	14.32	0.81	9.63
February 4, 1933	16½	17.05	0.47	7.68	16.58	0.58	7.92	....	...	....
March 30, 1933	18½	17.86	0.38	7.35	17.72	0.39	7.44	....	...	....
May 16, 1933	20	17.43	0.47	7.52	17.56	0.47	7.47	....	...	....
August 15, 1933	23	18.45	0.33	7.04	17.98	0.37	7.21	....	...	....
October 17, 1933	25	18.50	0.26	7.00	18.58	0.25	6.99	....	...	....

TABLE XIV

Comparison of the weights and juice quality of different sections of tasseled and untasseled stalks from the same stools

	Weights in Pounds				Per cent Sucrose in Juice			
	Bottom 3′	Middle	Top 3′	Millable green-leaf	Bottom 3′	Middle	Top 3′	Millable green-leaf
Tasseled	2.88	8.19	2.79	1.22	16.32	16.38	15.79	12.62
Not tasseled	2.66	6.07	2.31	1.00	14.97	16.00	16.27	13.29

TABLE XV

Percentage of total nitrogen in the first- and second-season cane*

	First-season cane			Second-season cane		
	Green top	Millable green-leaf	Dry-leaf	Green top	Millable green-leaf	Dry-leaf
Before N was applied.....	0.749	0.146	0.106	0.673	0.122	0.122
2 days after N was applied.....	0.730	0.150	0.108	0.594	0.116	0.095
4 " " N " "	0.816	0.201	0.116	0.676	0.108	0.093
7 " " N " "	0.735	0.162	0.127	0.598	0.118	0.106
2 weeks " N " "	0.757	0.122	0.085	0.685	0.166	0.135
3 " " N " "	0.784	0.162	0.099	0.749	0.127	0.100
4 " " N " "	0.933	0.192	0.094	0.930	0.217	0.113
5 " " N " "	0.949	0.224	0.113	1.012	0.170	0.127
11 " " N " "	0.890	0.220	0.130	0.854	0.240	0.118

* First-season cane is normally the stalks that come up within the year of planting. In this paper first-season cane includes cane up to fourth order. Fifth and higher orders are second-season cane.

Showing the March-planted cane (big cane) to the right and the September-planted cane (small cane) to the left. The right end stools of small cane were shaded in the forenoon by the big cane. These stools were late in stooling out and at harvest the stalks weighed less and had less sucrose than the stools towards the left which received full sunlight.

All the stalks shown in the picture grew originally from one single eye of cane. This one stool is from an outside row of cane and it contains stalks ranging in age from 4 months to 18 months. This is an extreme case to be sure, but this illustrates that under favorable conditions of light, space, and food, suckering is a continuous process in a field of cane.

Showing the quantity of cane of different orders harvested from one inside line of cane in this experiment. At the time of harvest the field was 20 months old.

This illustrates that in a first-season cane, the green-leaf part (the part containing little sucrose and much impurity) constitutes only a seventh or an eighth of the whole stalk. In the second-season sucker, this green part is fully half as much as the whole stalk. The relative proportion of this green part of the stalk to the rest of the stalk has a very important bearing on the average richness of the whole stalk.

The stick to the left is a sucker of the fifth order. At the time of harvest it was 10 months old. To the right is a lala growing from a first-season cane, only part of which is shown. This lala is also 10 months old, but the richness of juice of the lala is very much higher than the fifth-order shoot with which it is comparable in age and nearly approaches the richness of the first-season cane on which this lala is growing.

Here are three stalks in different stages of vigor as shown clearly by the manner of growth of the tops—by the spread and number of leaves, etc. The most vigorous one on the extreme left has a large green-leaf section, the one on the extreme right a very small green-leaf section of millable cane. It is suggested that the maturity of a stalk can well be judged by noting the length of this green-leaf part and the proportion it bears to the whole stalk.

The above illustration shows a first-season cane from September planting carrying four millable lalas; such stalks are not common in a cane field. All these lalas had as good juice as the mother stalk and are referred to in the text under the heading "Lalas."

Boron Deficiency Symptoms In Sugar Cane

By J. P. Martin

Introduction

In recent years, plant physiologists have demonstrated that small amounts of chemical elements such as manganese, boron, zinc and copper are essential for normal plant growth. Previous to this, only ten elements were considered necessary for plant growth, namely, carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and iron.

It has been shown by Lee and McHargue (5), Davis (2), and Martin (6), that manganese is essential for the growth of sugar cane in soil, sand or water cultures. Moir (11) stated that small amounts of manganese are necessary for cane growth under field conditions at Olaa Sugar Company, Ltd., Hawaii. Allison (1), in Florida, reported an excellent growth response with sugar cane when manganese and copper were applied to specific types of soil. The soil, which received copper at the rate of 75 pounds per acre of copper sulphate, produced a normal stand of cane, whereas a total growth failure resulted in the untreated areas. McHargue (9) has demonstrated the importance of small quantities of manganese in relation to the growth of Kentucky blue grass.

Johnston (3) has shown that the potato plant required one-half of a part per million of boron for normal growth, and that 5 p. p. m. were extremely toxic to the plant. Sommer (12) found that small quantities of boron were essential for the growth of peas, sunflowers, lettuce, barley, sugar beets and many other plants. Warington (14, 15) proved that boron was essential for the growth of the broad bean. Johnston and Dore (4) established the fact that boron is essential for the growth of the tomato plant. Sommer and Lipman (13) have presented evidence "on the indispensable nature of zinc and boron for higher green plants." McHargue and Calfee (10) demonstrated that lettuce plants grown in nutrient solutions containing quantities of boron from 0.4 to 0.9 p. p. m. produced a vigorous growth with no evidence of boron deficiency. However, with the 0.9 p. p. m., a slight toxic effect was noticed, while concentrations above this amount proved to be decidedly toxic.

In Java, van den Honert (16) found that a trace of boron was essential for normal growth of the sugar cane plant. His investigations, which had to do with the nutrition of the variety P. O. J. 2878, were carried out in sand cultures. He stated that 0.1 mg. of boron per liter of soil solution was sufficient for normal growth. A number of other references might be cited where elements in small amounts only have been found necessary for plant growth.

Martin (8) has shown that a depressed or retarded cane growth results when any one of eight of the essential elements is omitted in sand or water cultures. In each case specific leaf and stalk symptoms of malnutrition were manifested by the cane plant. Under field conditions the growth of the cane plant depends largely on the presence and availability of the essential elements in the soil. A

deficiency of one of these elements in the soil may be the limiting factor for cane growth, and specific leaf and stalk symptoms of malnutrition appear on the plants in the field as a result of such a deficiency. The deficiency symptoms that develop on the cane plants in the field are proving to be similar to those that occur on plants grown in sand or water cultures. Thus the diagnosis of the cause of certain growth failures (malnutrition type) occurring in various sugar cane fields has been expedited by a knowledge of these nutritional deficiency symptoms artificially produced on plants grown in culture solutions.

The object of this paper is to describe the symptoms of boron deficiency as produced on sugar cane grown in water cultures, in order that these symptoms may readily be recognized should they appear on sugar cane growing under field conditions. The studies reported herein were started during the early part of 1933 and were completed in January, 1934.

Experimental Procedure

The nutrient solution employed in these studies was one that, in previous nutritional investigations by the writer, proved to be extremely favorable for the growth of sugar cane. The chemical composition of this solution is given in Table I, while the p. p. m. of each element are presented in Table II.

Chemically pure salts, "Baker's Analyzed," and distilled water were used throughout these experiments; no attempt was made to purify the chemicals used. The fact that boron-deficiency symptoms developed on the cane plants in the boron-free solutions showed the chemicals to be exceptionally free from boron.

The hydrogen-ion concentration of the nutrient solution had a pH value of 5.2. In earlier studies, Martin (7) showed that the optimum pH value for the growth of sugar cane in water cultures is 4.8 to 5.2.

TABLE I

Partial Volume Molecular Concentrations per Liter of Compounds in the Nutrient Solution

Compound	V. M. C.
KH_2PO_4	.001
KNO_3	.003
$Ca(NO_3)_2.4H_2O$	.003
$CaCl_2.6H_2O$	.004
$MgSO_4.7H_2O$	.001
H_3BO_3	.00002
$Na_2SiO_3.9H_2O$	.00001

Iron and manganese were added at the rate of 10 and .25 p. p. m. per liter from $FeSO_4.(NH_4)_2\ SO_4.6H_2O$, and $MnSO_4$, respectively.

TABLE II

Parts per Million of Each Element in the Nutrient Solution

Element	P. P. M.
Nitrogen	126
Phosphorus	31
Potassium	156
Calcium	280
Magnesium	24
Sulphur	32
Chlorine	284
Iron	10
Sodium	.23
Silica	.28
Boron	.22
Manganese	.25

Cuttings of the following sugar cane varieties, H 109, P. O. J. 36, P. O. J. 2878, Yellow Caledonia and Badila, were germinated in black volcanic sand. Tap water was applied to the sand during the germination of the cane cuttings. Shoots of uniform size approximately 12 to 14 inches in height were removed from the cuttings and transferred to the complete nutrient solution which contained boron. The majority of the young shoots had developed shoot roots and a well-established root system quickly developed on the plants in the nutrient solution. These plants were grown in the complete nutrient solution for five weeks in order that plants of a uniform size might be selected for the experiment. During this period the cane plants made what was considered a normal growth.

The containers used in these studies were one-gallon earthenware jars having a glazed inner surface. A two-piece lid of redwood with a 1.5-inch hole in its center was made so that it covered the top of the container. The cane plant was placed through the hole of the cover and held firmly in an upright position by placing two halves of a large cork around the plant and then by placing the cork and the plant as a unit tightly into the circular hole in the cover. With this arrangement the position of the plant could easily be adjusted and the root system readily examined at all times.

Plants of a uniform size which had been growing for five weeks in the complete nutrient solution were selected. One-half the number of plants of each variety received the complete nutrient solution, while the other half received the minus-boron solution. At first, the nutrient solutions were changed once a week but later, as the plants developed, it was necessary to renew the solutions once every four or five days.

For the purpose of studying the growth of the cane plants when boron was omitted, only two nutrient solutions were necessary. In other words, the growth of the plants in the complete nutrient solution was compared with the growth of plants of similar age in a boron-free solution, the only difference being the presence of .22 p. p. m. of boron in the former solution as against the absence of this amount of boron in the latter solution.

External Symptoms

The most marked effect upon the cane plants when grown in the boron-free nutrient solution was the retardation of growth, the development of distorted leaves, the chlorotic condition of the young leaves and the presence of definite lesions on the leaves and within the stalks. The plants quickly died if boron was not returned to the culture solution. The depressed growth, the distorted leaves, the chlorotic leaf condition and, to some extent, the leaf symptoms are shown in Figs. 1 and 2. The leaf symptoms are shown in greater detail in Figs. 3 and 4.

The young leaves of P. O. J. 36 (Fig. 1) which developed in the minus-boron solution became very much shortened in length and narrowed in width at the base. The young leaves also became chlorotic. The edges and tips of the affected leaves developed irregularly which made it appear as though portions of the leaves had fallen away; the edges of the tissue so affected were dark reddish brown to black in color. The irregular edges had a burned appearance. When boron was again added to the nutrient solution this particular plant resumed a normal growth.

The H 109 plant on the right in Fig. 2 also shows the distorted and chlorotic condition of the young leaves. The growth of this plant was very much depressed when compared with the growth of plants of similar age which received boron (Fig. 2, left).

The first leaf symptoms to develop, as a result of boron deficiency, appeared on the young leaves as minute, elongated, watery spots. The initial spots or lesions developed parallel to the vascular bundles of the leaves and produced a definite leaf striping (Fig. 3, A, B). In one experiment leaf symptoms were observed at the end of 30 days but, as a rule, the first symptoms developed from one to two months after boron was omitted from the nutrient solution.

The initial lesions soon began to enlarge and were characterized on the upper and lower leaf surfaces by small, longitudinal, sunken areas or depressions in the center of the lesion while, on the lower leaf surfaces, minute, elongated, gall-like bodies frequently developed. The upper and lower leaf symptoms are shown in Figs. 3 and 4.

Three to four weeks after the first symptoms appeared many of the lesions were 3 to 10 mm. in length and 1 to 3 mm. in width; in some instances individual lesions measured 20 to 50 mm. in length and 2 to 5 mm. in width.

The more mature lesions manifested a dark red center surrounded by chlorotic tissue. In the mature lesions the leaf tissues separated, forming a definite crack or fracture in the leaf. The inner edges of the leaf fracture were serrate, giving the appearance of ladder-like or chain-like lesions (Fig. 4).

In a few instances stalks manifested internal narrow, brownish streaks at and slightly below the growing point. These lesions varied from 1 to 20 mm. in length and from 1 to 2 mm. in width. Occasionally these longitudinal lesions in the stalk showed the ladder-like arrangement somewhat similar to those in the leaf. No external stalk symptoms were observed on the plants which were grown in the boron-free nutrient solution.

Fig. 1. Showing the development of P. O. J. 36 in a boron-free nutrient solution. The young leaves are chlorotic and badly distorted. This plant made a normal growth when boron was again added to the nutrient solution.

Fig. 2. H 109 cane plants. The plant on the left received boron, while the plant on the right was deprived of boron. Note the depressed growth and the distorted leaf development of the latter.

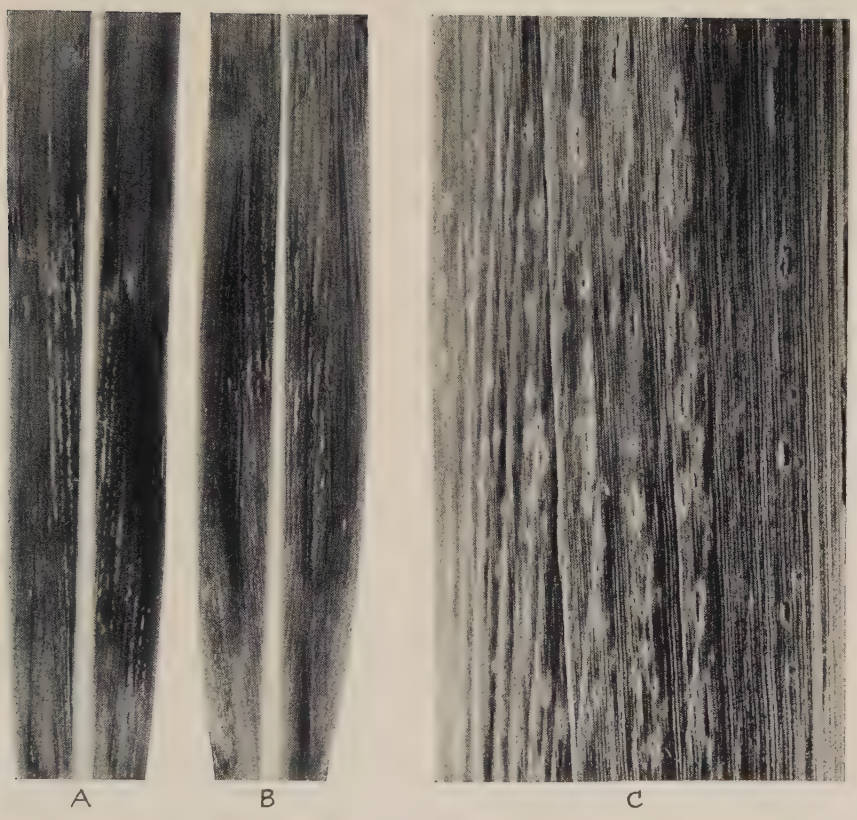

Fig. 3. Leaf symptoms of boron deficiency on H 109 cane. Leaves A and B show a definite striping which develops parallel to the vascular bundles and a narrowing of the leaves at the base. On the lower surface of these leaves, small longitudinal gall-like bodies develop as shown in C. (A, B×0.5; C×3.2.)

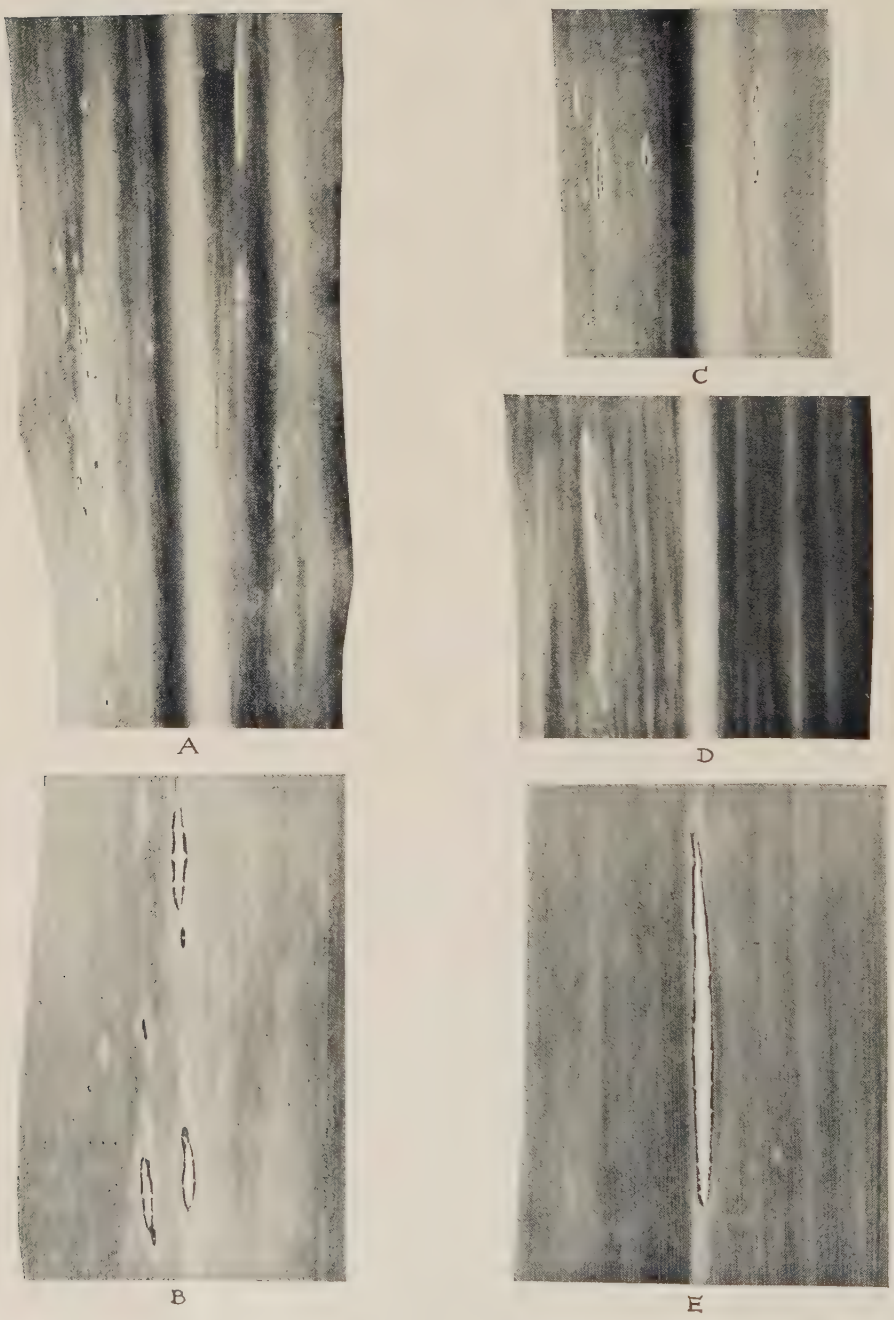

Fig. 4. Leaf symptoms of boron deficiency on Badila cane. A(×1.5), the development of the youngest to the oldest lesions on upper leaf surface. B (×3), an enlarged section of left center of A. C (×1.3), leaf symptoms on lower leaf surface. D (×1.9), a longitudinal lesion and a few of the earliest symptoms on the upper leaf surface. E (×3), an enlargement of D, note the serrate edges of the open leaf crack.

Microscopic Symptoms

A histological study of the lesions that appeared on the leaves showed a derangement of cells within certain tissues. Transverse sections of these lesions in various stages of development were made from fresh as well as from fixed and embedded material.

The transverse sections shown in Fig. 5 were taken from leaves of Badila cane on which boron-deficiency symptoms developed. Although normal in many respects, it is seen (Fig. 5, A) that the lignified fiber cells (hypodermal sclerenchyma) at the upper and lower sides of the large chlorophyll-bearing bundle sheath appear to be loosely organized, small in size, irregular in shape, and poorly developed. Many vascular bundles were examined and this condition seemed to be quite general, as again shown in Fig. 6, A, B. One characteristic of these fiber cells when normal is their high lignin and silica content which explains their degree of hardness and tensile strength. This abnormal condition, associated with boron deficiency, suggests an existing relationship between silica metabolism and boron deficiency.

A cross section through one of the earlier stages of a leaf lesion shows (Fig. 5, B, C,) that certain of the lower cells in the chlorophyll-bearing bundle sheath have become greatly enlarged and drawn toward the lower leaf surface. Normally, these particular cells have the form of short cylinders with the long axis of the cell parallel to the vascular bundles (the veins of the leaf). This abnormal cell development may occur between the large rhomboid and small round bundles or between the latter and the medium large oval bundles. Later, this stimulated cell growth pushes through the lower leaf surface (Fig. 5, D, E) and appears as elongated gall-like bodies on the lower leaf surface (Fig. 3, C) between the large vascular bundles.

Transverse sections, through young leaf lesions having elongated reddish to dark brown centers, showed that necrotic tissue extends through the leaf, which, at this point, becomes deeply constricted (Fig. 5, F, G). Here again the lesion develops between two vascular bundles and extends from the lower to the upper leaf surface. These constrictions apparently account for the depressions that occur in the center of the lesions, as shown in Fig. 4, A, B. The leaf tissues in the lesion at this stage are greatly weakened and eventually split, thus forming open cracks in the leaves, also shown in Fig. 4.

Transverse sections through a leaf lesion where the leaf split has not as yet developed is shown in Fig. 5, H, I. In each case the constriction is much deeper on the lower than on the upper surface of the leaf; the epidermis is distorted and broken and the development of the tissue is abnormal.

No abnormal development of the phloem or xylem was observed other than a possible crowding effect which resulted from the greatly enlarged bundle sheath cells. However, these tissues become involved in the advanced development of the lesions before the leaf fractures develop.

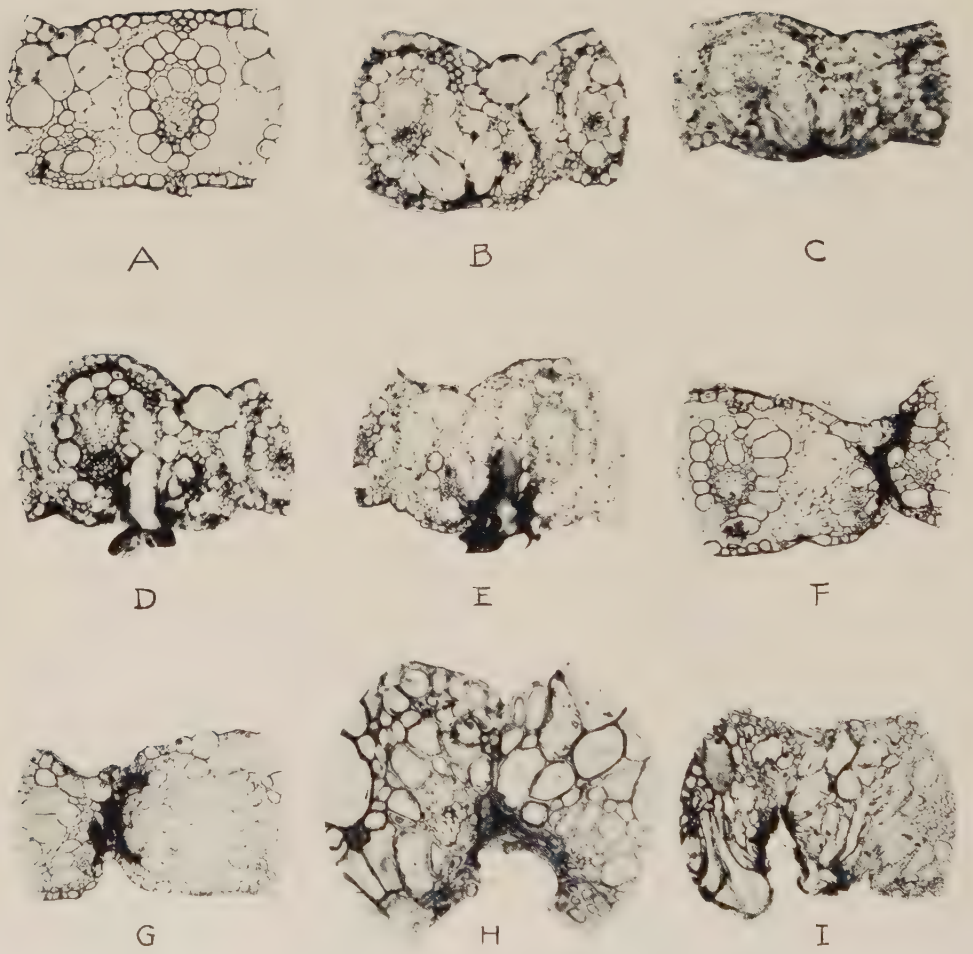

Fig. 5. Transverse sections of leaves of Badila cane grown in a boron-free nutrient solution. A, normal structure. B and C, the greatly enlarged cells in the chlorophyll-bearing bundle sheath which develop between two vascular bundles and the tendency of these "giant cells" to focus at a point near the lower leaf surface. D and E, the stimulated cells which have pushed through the lower epidermal surface to form the elongated gall-like body on the lower leaf surface. F and G, the deep constrictions and necrotic tissues extending through the leaf; at these points the leaf is weakened and the tissue eventually separates, thus forming open leaf cracks; also, in F, the enlargement of the cells of the chlorophyll-bearing bundle sheath on the right side of the large, vascular bundle. H and I, lesions where the open leaf crack has not fully developed, the constrictions being much deeper on the lower than on the upper leaf surface. A, B, C, D, E, F, G and I, × 95; H, × 190.

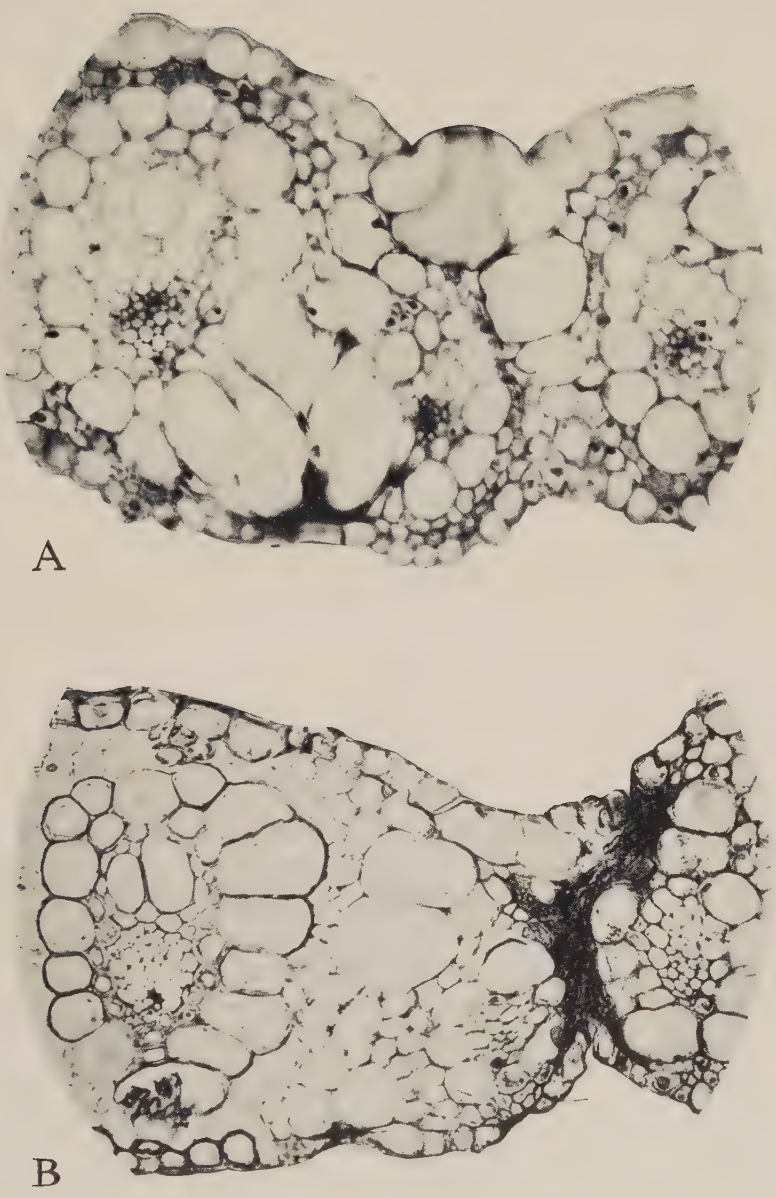

Fig. 6. A and B, enlargements of the sections shown in Fig. 5 of B and F, respectively.

Discussion

Symptoms similar to those described above were observed in 1931 on the variety Molokai 1575. At that time the leaf symptoms on Molokai 1575 resembled those of pokkah boeng disease of sugar cane, which is caused by the fungus *Fusarium moniliforme* Sheldon.

The leaf and stalk symptoms that developed on the cane varieties when grown in boron-free water cultures were in the majority of cases similar to the symptoms of pokkah boeng disease. Histological studies of the lesions, induced by omitting boron in the nutrient solutions, revealed no evidence of micro-organisms being present in the diseased tissue.

Since the symptoms of boron deficiency and those of pokkah boeng disease of sugar cane are in many respects similar, it is suggested that the severity of pokkah boeng disease might be associated with a boron deficiency in the sugar cane plant.

The role of boron in plant metabolism has not been definitely established. Boron is apparently essential for the normal development of those parts of the plant which are capable of making further growth. A degeneration of the growing parts of the plant takes place when a deficiency of boron occurs.

Summary

1. An abnormal growth resulted when sugar cane was grown in boron-free water cultures.

2. A normal growth was resumed when as little as .22 p. p. m. of boron was added to the nutrient solution.

3. A small amount of boron is essential for normal cane growth in water cultures.

4. The boron-deficiency symptoms developing on the cane plants were characterized by depressed growth, the development of distorted and chlorotic leaves and the presence of definite leaf and stalk lesions.

5. When cane plants were deprived of boron the meristematic or growing parts of the plants were seriously affected. If boron was not supplied to the nutrient solutions the plants soon died.

Acknowledgment

The writer wishes to express his appreciation to D. M. Weller for his assistance in relation to the histology of the problem and for the photomicrographs accompanying this paper.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 18, 1933, TO DECEMBER 14, 1933.

Date	Per Pound	Per Ton	Remarks
Sept. 18, 1933	3.65¢	$73.00	Cubas.
" 19	3.62	72.40	Cubas.
" 20	3.62	72.40	Cubas.
" 25	3.60	72.00	Cubas.
" 27	3.59	71.80	Cubas.
" 28	3.56	71.20	Cubas, 3.57, 3.55.
" 29	3.53	70.60	Cubas.
Oct. 4	3.55	71.00	Cubas.
" 5	3.53	70.60	Cubas.
" 9	3.45	69.00	Cubas.
" 10	3.407	68.13	Cubas, 3.45, 3.40, 3.37.
" 13	3.34	66.80	Cubas, 3.35, 3.33
" 16	3.28	65.60	Cubas.
" 17	3.25	65.00	Cubas.
" 19	3.215	64.30	Philippines, 3.23; Cubas, 3.20.
" 27	3.30	66.00	Cubas.
Nov. 9	3.35	67.00	Cubas.
" 10	3.30	66.00	Cubas.
" 13	3.20	64.00	Cubas.
" 17	3.18	63.60	Philippines.
" 20	3.15	63.00	Cubas.
Dec. 4	3.27	65.40	Cubas.
" 5	3.275	65.50	Cubas, 3.25, 3.30.
" 11	3.23	64.60	Cubas.
" 14	3.19	63.80	Cubas.

CIRCULAR NO. 62

EXPERIMENT STATION

OF THE

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Annual Synopsis of Mill Data 1933

BY

W. L. McCLEERY

HONOLULU, HAWAII
DECEMBER, 1933

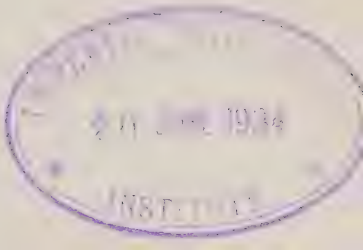

TABLE NO. 1

VARIETIES OF CANE

(Comprising one per cent or more of total crop)

	H 109	Y. C.	D 1135	P. O. J. 36	Yellow Tip	Striped Tip	K 107	P. O. J. 2878	Badila	Others
H. C. & S. Co.	100	...	...	..	..	..	..	..	..	..
Oahu	93	...	6	..	..	..	..	..	..	1
Ewa	99	...	...	..	..	..	..	1	..	..
Waialua	95	...	3	1	..	..	..	..	..	1
Maui Agr.	100	...	...	..	..	..	..	..	..	..
Pioneer	99	...	. .	..	..	..	..	..	..	1
Lihue	47	...	3	15	12	1	..	..	8	14 (1)
Olaa	...	71	23	5	..	..	..	..	..	1
Haw. Sug.	97	...	2	..	..	..	..	..	..	1
Kekaha	98	...	...	..	..	..	..	..	..	2
Honolulu	91	...	...	1	..	..	..	6	..	2
Haw. Agr.	...	13	72	..	..	..	..	..	..	15 (2)
Onomea	...	61	13	20	2	..	..	..	..	4
Hilo	...	83	15	2	..	..	..	..	..	..
Honokaa	...	1	60	10	..	..	..	5	..	24 (3)
Makee	40	6	...	18	6	..	..	..	8	22 (4)
McBryde	80	1	4	7	2	..	..	..	..	6
Wailuku	85	...	4	1	..	..	..	8	..	2
Hakalau	...	56	28	8	6	..	..	..	..	2
Kahuku	90	2	...	1	..	..	..	5	..	2
Laupahoehoe	...	34	61	..	3	..	..	..	..	2
Waiakea	...	98	...	..	..	..	..	..	..	2
Koloa	54	...	...	11	30	.	..	..	..	5
Hutchinson	...	37	45	17	..	..	..	..	..	1
Hamakua	...	10	78	1	4	..	..	..	..	7
Paauhau	...	1	47	28	14	..	..	..	..	10
Pepeekeo	...	97	1	1	..	..	..	.	..	1
Kohala (Hawi)	...	...	13	5	..	45	32	..	..	5
Kohala	1	...	13	..	..	13	61	..	..	12 (5)
Honomu	...	57	9	25	..	..	..	3	..	6
Kaiwiki	...	7	82	..	9	..	..	..	..	2
Waimanalo	34	...	1	19	..	..	..	34	..	12 (6)
Kilauea	...	2	2	2	8	1	..	5	49	31 (7)
Waianae	100	...	...	..	..	..	..	..	..	..
Union Mill	...	...	10	..		77	13	..	..	..
Kaeleku	2	72	1	14	..	..	..	7	..	4
Niulii	...	...	37	5	..	52	3	..	..	3
Waimea	99	..	...	..	..	..	..	1	.	..
Average 1933	54.2	15.5	13.2	4.6	2.1	1.8	1.4	1.3	1.2	4.7
" 1932	54.5	17.6	13.4	4.1	2.1	1.5	0.9	0.2	1.0	4.7
" 1931	54.2	18.8	13.7	2.6	3.0	2.1	1.0	..	0.7	3.9
" 1930	56.6	19.9	12.3	0.7	3.5	1.6	..	..	1.2	4.2
" 1929	53.1	21.5	13.0	0.3	4.3	2.1	..	..	0.5	5.2
" 1928	54.7	20.7	12.9	..	4.9	2.2	..	..	0.3	4.3
" 1927	53.1	23.7	11.8	..	4.0	1.6	..	..	0.4	5.4
" 1926	48.7	25.6	12.1	..	4.5	2.1	..	..	0.5	6.5
" 1925	42.7	30.7	11.9	..	2.7	2.1	..	..	0.4	9.5
" 1924	38.1	32.6	12.0	..	2.3	2.0	..	..	0.1	12.9

(1) H. 456 ..... 7%
(2) P. O. J. 213 ..... 2%
(3) P. O. J. 213 ..... 4%
Uba 16%
(4) Manoa 213 ..... 10%
H 9806 ..... 6%
(5) K 202 ..... 11%
(6) Uba 7%
(7) Uba 17%
U. D. 1 ..... 8%

Annual Synopsis of Mill Data

By W. L. McCleery

Operating data from the 38 factories of the Association are included in this report. Sugar production, as covered by these Synopsis data for the year ending approximately September 30, amounts to 1,026,870 tons. While this is a slightly larger amount than reported for any previous year, the increase is less than 1 per cent. The increase the past five crops has averaged about two and one-half per cent per year.

Factories are listed in the tables in the order of sugar production for the previous five crops unless otherwise noted.

Complete cane mill and factory equipment data are given in the large table inserts for the first time in several years. In the first table all losses have been grouped under one heading and are on a sucrose basis. Milling results have also been grouped at the beginning of this table.

Changes in the small tables include:

Enlargement of the final molasses table to include remelt sugar data. This is now Table 8.

Comparison basis of actual and theoretical recoveries in Table 9 changed from 37.5 to 30 gravity purity final molasses with the 100 per cent extraction and no other losses, remaining as before. The second comparison in this table has been called Recovery Ratio with the basis unchanged, that is, cane ratio corrected to sugar ratio.

Cane Varieties

Nine varieties this year are classed as comprising 1 per cent or more of the total crop. K 107 and P. O. J. 2878 now appear in Table 1 for the first time and Uba, which had increased to 1.0 per cent last year, has declined to the minor variety classification.

H 109 has for the last three years practically held its average of a little over 54 per cent after having reached a peak of 56.6 per cent in 1930. Yellow Caledonia has shown a consistent decline since 1921. D 1135, Yellow Tip, Striped Tip, and Badila do not show material changes. P. O. J. 36 has made a gradual increase the past five years to the present figure of 4.6 per cent.

Minor Varieties:

Eleven other canes classed as minor varieties are given in the tabulation below. They comprise less than 1 per cent of the total crop, but are 1 per cent or more of the crop at certain factories and are listed in this tabulation as per cent of total crop.

1. Uba	.81	5. P. O. J. 213	.30	9. Mc.B. 7	.04
2. H 456	.41	6. Manoa 213	.29	10. U. D. 110	.03
3. U. D. 1	.41	7. H 9806	.17	11. U. D. 4	.01
4. K 202	.32	8. Manoa 127	.04		

Manoa 127, U. D. 110, U. D. 4 and McB. 7 are additions this year, though the latter variety was so included in 1931. The following minor varieties reported last year do not appear: H 8965, U. D. 50, Striped Mexican, K. K. 456, McB. 6, U. D. 79, N Uba and Nalo 13.

Striped Mexican, which has now been dropped, was in the major classification from 1919 to 1927, though at its peak in 1923 the amount was only 3.1 per cent.

Quality of Cane

Quality of cane by islands and the averages for the whole group are listed in Table 2. The average quality ratio is the best since 1926 and stands at 8.49, or 0.35 better than last year. There has been a decided improvement on each island except Kauai, which is poorer by 0.15. Additional information on cane quality for the present year is given in the tabulation below:

	Hawaii Best Since	Maui Best Since	Oahu Best Since	Kauai Poorest Since	Average Best Since
Pol Per Cent	1926	1920	1929	Low Record	1929
Purity, 1st Exp. Juice	1925	1929	1915	1928	1926
Quality Ratio	1926	1920	1929	1928	1926

Chemical Control

Boiling-house comparisons of actual and theoretical recoveries are in the same form as last year in Table 3. Twenty factories show over 100 per cent recovery on available and three (on a sucrose basis) over 101 per cent, or one less each than last year.

Molasses produced on theoretical is listed in the same form as previously, in Table 3. The average for both sets of calculations has for many years been close to 90 per cent on theoretical. Abnormally high figures are shown for Honolulu, Hawaiian Agricultural Company, Kaiwiki and Kaeleku.

Table 4 gives gravity solids and sucrose balances for all factories except the three not reporting sucrose. Two factories report data, giving a negative undetermined loss of solids, and two other factories show a negative undetermined sucrose loss.

Table 5 contains sucrose data with true averages in the same form as last year except that sucrose undetermined loss appears with the other losses in the first large table.

Data submitted this year include:

Complete sucrose data from all factories, except Honokaa, Kaeleku and Waimea, representing 96.4 per cent of this year's sugar production.

Mixed juice weights from all factories except Kohala and Kaeleku, at which factories the reported weights are calculated from volumes.

Molasses scale weights from 32 factories. Factories not weighing molasses are Hamakua, Kaiwiki, Kaeleku, Kohala, Niulii and Waiakea.

Turbidity of juice to evaporators reported from all factories except Hawaiian Agricultural Company, Wailuku, Kilauea and Niulii.

TABLE NO. 2

COMPOSITION OF CANE BY ISLANDS

	Hawaii	Maui	Oahu	Kauai	Whole Group
1924					
Pol	12.44	14.34	13.48	13.34	13.26
Per cent Fiber	12.99	12.16	12.72	12.94	12.74
Purity 1st Expressed Juice	87.98	89.19	87.02	87.31	87.86
Quality Ratio	8.78	7.53	8.10	8.06	8.19
1925					
Pol	12.35	14.42	13.52	13.24	13.22
Per cent Fiber	12.92	12.40	12.60	12.91	12.74
Purity 1st Expressed Juice	88.02	89.36	87.11	87.19	87.92
Quality Ratio	8.84	7.42	8.12	8.15	8.22
1926					
Pol	12.53	14.66	13.40	13.03	13.24
Per cent Fiber	12.90	12.24	12.72	12.46	12.65
Purity 1st Expressed Juice	87.59	89.03	86.61	86.68	87.45
Quality Ratio	8.73	7.36	8.23	8.33	8.24
1927					
Pol	11.34	14.00	12.61	12.07	12.32
Per cent Fiber	12.84	11.98	12.29	12.65	12.49
Purity 1st Expressed Juice	86.27	87.85	85.87	85.17	86.28
Quality Ratio	9.73	7.71	8.78	9.11	8.91
1928					
Pol	11.57	14.13	13.09	12.09	12.55
Per cent Fiber	12.58	12.56	12.13	12.82	12.50
Purity 1st Expressed Juice	86.60	88.76	86.84	85.16	86.84
Quality Ratio	9.54	7.55	8.39	9.11	8.72
1929					
Pol	11 80	14.56	13.49	12.64	12.90
Per cent Fiber	12.53	13.24	12.28	12.61	12.62
Purity 1st Expressed Juice	86.65	89.14	87.17	85.97	87.18
Quality Ratio	9.45	7.35	8.14	8.69	8.50
1930					
Pol	11.30	13.77	13.05	12.67	12.49
Per cent Fiber	12.73	12.92	12.35	12.57	12.63
Purity 1st Expressed Juice	86.59	88.60	86.98	86.34	87.04
Quality Ratio	9.84	7.79	8.42	8.55	8.76
1931					
Pol	11.51	14.30	13.17	12.55	12.63
Per cent Fiber	12.52	13.04	11.98	12.75	12.53
Purity 1st Expressed Juice	86.18	88.26	86.31	85.49	86.47
Quality Ratio	9.66	7.52	8.42	8.73	8.72
1932					
Pol	11.16	14.02	13.23	12.35	12.42
Per cent Fiber	12.44	13.06	12.29	12.63	12.56
Purity 1st Expressed Juice	86.25	88.71	87.15	85.69	86.86
Quality Ratio	10.05	7.63	8.27	8.89	8.84
1933					
Pol	11.99	14.88	13.39	12.01	12.86
Per cent Fiber	12.47	13.08	12.42	12.35	12.54
Purity 1st Expressed Juice	87.60	89.02	87.25	85.35	87.33
Quality Ratio	9.20	7.23	8.17	9.04	8.49

TABLE NO. 3

TRUE BOILING-HOUSE RECOVERY

Comparing per cent sucrose available and recovered

Factory	Available	Obtained	% Recovery on Available	Molasses Produced on Theoretical	
				s. j. m. Formula	Gravity Solids*
H. C. & S. Co.	93.75	93.62	99.9	95.0	94.8
Oahu	93.86	94.47	100.6	88.4	93.7
Ewa	93.23	92.89	99.6	97.6	95.9
Waialua	92.82	93.41	100.6	87.9	92.6
Maui Agr.	92.99	94.19	101.3	78.7	84.4
Pioneer	92.73	92.08	99.3	94.4	93.4
Lihue	91.65	92.43	100.9	91.5	96.5
Olaa	92.71	92.75	100.0	93.8	95.4
Haw. Sug.	92.92	93.69	100.8	92.7	101.2
Kekaha	92.55	91.39	98.7	99.6	96.4
Honolulu	92.56	90.94	98.2	111.4	102.6
Haw. Agr.	92.16	90.50	98.2	105.1	97.6
Onomea	92.41	93.00	100.6	85.1	86.5
Hilo	92.26	92.71	100.5	92.9	95.4
Honokaa†	89.21	89.01	99.8	....	91.3
Makee	89.14	89.28	100.2	85.0	85.2
McBryde	90.76	90.36	99.6	94.6	94.3
Wailuku	92.58	92.52	99.9	92.5	93.3
Hakalau	92.98	93.20	100.2	89.5	90.6
Kahuku	91.68	92.85	101.3	88.0	94.3
Laupahoehoe	94.39	93.92	99.5	88.8	87.3
Waiakea	93.03	93.02	100.0	91.7	92.7
Koloa	91.67	91.81	100.2	90.3	92.4
Hutchinson	92.90	93.67	100.8	88.3	92.6
Hamakua	90.96	91.94	101.1	64.6	67.7
Paauhau	89.47	87.92	98.3	98.6	93.2
Pepeekeo	92.67	93.00	100.4	91.8	92.2
Kohala (Hawi)	88.68	88.84	100.2	78.5	80.3
Kohala	90.90	88.05	96.9	95.1	85.0
Honomu	91.47	92.03	100.6	90.6	96.1
Kaiwiki	91.57	89.88	98.2	110.6	103.6
Waimanalo	89.04	89.74	100.8	89.1	91.6
Kilauea	88.62	87.85	99.1	87.2	86.4
Waianae	93.51	92.33	98.7	91.7	87.6
Union Mill	91.44	90.65	99.1	82.8	80.1
Kaeleku†	89.03	93.41	104.9	....	140.3
Niulii	89.60	88.57	98.9	73.9	72.7
Waimea†	92.55	89.93	97.2	....	80.0

* The theoretical amount of gravity solids in final molasses assumed to be gravity solids in syrup, less solids accounted for in commercial sugar.

† As sucrose in syrup and sugar have not been reported, gravity purities have been estimated by adding 0.8 and 0.3 to the apparent purities of syrup and sugar.

Milling

Extraction at 97.57 and an extraction ratio of 19.4 have again broken previous records. "Milling Loss" is slightly poorer than the record established last year. The actual sugar lost in bagasse per 100 sucrose in cane is, however, the lowest on record. The average grinding rate, 55.38 T. C. H., increased 4.6 per cent to a new high figure. The tonnage ratio and tonnage fiber ratio are also new records.

High extraction this year has been aided by an increase in cane pol of .44. There was also an increase in mill dilution to 34.28 per cent, which is higher than in recent years. Roller pressure increased from 70.8 tons per foot to a new high figure of 71.7 tons. There were no important additions to milling equipment.

No milling records of individual factories for extraction, extraction ratio or milling loss have been broken. Eight factories report extraction of 98 or over, or the same number as last year. Six report under 2.0 milling loss, or three less than in 1932.

The difference in purity between first expressed juice and mixed juice for factories basing control on mixed juice is 2.82. This is next to the lowest figure on record, reached some years ago, and is an encouraging condition, for with more intensive milling a larger purity drop would be expected. The smaller difference in rcent years can be attributed to less juice deterioration because of faster milling and more sanitary conditions around the mills obtained by the increased use of non-strained juice pumps and of copper linings under the mills and in the juice troughs.

Table 6 of milling results is given in the same form as previously, with the factories listed in the order of milling loss. Factories that have improved their position materially are Pepeekeo, H. C. and S. Co., Hawaiian Sugar, Waimea, Waiakea, Makee and Honolulu. Factories having correspondingly lower positions are Waialua, Paauhau, Hawi, Lihue and Hamakua. Most of the factories having lower positions increased their grinding rates, necessitating a lower dilution, thus giving poorer milling results.

Boiling-House Work

All former recovery records have been exceeded this year. The contributing factors are higher juice purities and lower losses in filter cake, molasses and undetermined.

Clarification:

The average mixed juice pH has increased slightly to 7.97, with increases reported from 68 per cent of the factories.

Turbidity of juice to the evaporators is lower than last year and also poorer than previously reported. The average is 3.23, compared with 3.33 and 3.41 for the two previous years. Faster grinding is at least a contributing factor in this decrease.

Koloa factory installed a Dorr clarifier in place of settling tanks and reports an improved turbidity of 4.7 this year compared with 3.7 last year.

The amount of lime, as CaO per ton cane, is 1.25 pounds, the same low figure as last year.

TABLE NO. 4

GRAVITY SOLIDS AND SUCROSE BALANCES

Factory	GRAVITY SOLIDS PER 100 GRAVITY SOLIDS IN MIXED JUICE				SUCROSE PER 100 SUCROSE IN MIXED JUICE			
	Filter Cake	Commercial Sugar	Final Molasses	Undetermined	Filter Cake	Commercial Sugar	Final Molasses	Undetermined
H. C. & S. Co.	4.8	80.7	13.7	0.8	0.53	93.12	5.94	0.41
Oahu	5 1	79.9	13.7	1.3	0.13	94.35	5.43	0.09
Ewa	6 7	76.5	16.1	0.7	0.17	92.73	6.61	0.49
Waialua	4.3	79.3	14.9	1.5	0.24	93.19	6.31	0.26
Maui Agr.	...	84.1	13.4	2.5	....	94.19	5.52	0.29
Pioneer	4.9	77.1	16.5	1.5	0.23	91.87	6.86	1.04
Lihue	4.7	75 9	18.4	1.0	0.35	92.11	7.64	—0.10
Olaa	4.5	79.2	15.3	1.0	0.08	92.68	6.84	0.40
Haw. Sug.	3.7	79.6	16.1	0.6	0.21	93.49	6.56	—0.26
Kekaha	3.7	78.7	16.6	1.0	0.14	91.26	7.42	1.18
Honolulu	5.0	76.6	19.0	—0.6	0.38	90.59	8.29	0.74
Haw. Agr.	2.7	78.1	18.7	0.5	0.23	90.29	8.24	1.24
Onomea	4.1	79.3	14.6	2.0	0.18	92.83	6.46	0.53
Hilo	5.0	77.7	16.4	0.9	0.28	92.45	7.19	0.08
Makee	5.3	71.0	20.3	3.4	0.42	88.91	9.23	1.44
McBryde	4.2	73.0	21.3	1.5	0.19	90.19	8.74	0.88
Wailuku	4.9	78.4	15.5	1.2	0.46	92.09	6.86	0.59
Hakalau	4.6	79.2	14.7	1.5	0.28	92.94	6.28	0.50
Kahuku	5.8	74.6	18 1	1.5	0.32	92.55	7.32	—0.19
Laupahoehoe	3.1	82.0	12.9	2.0	0.12	93.81	4.98	1.09
Waiakea	5.0	78.9	14.8	1.3	0.41	92.64	6.39	0.56
Koloa	5.1	74.7	18.4	1.8	0.30	91.53	7.52	0.65
Hutchinson	5.2	77.8	15.6	1.4	0.15	93.53	6.27	0.05
Hamakua	...	79.3	14 0	6.7	....	91.94	5.84	2.22
Paauhau	5.4	73.3	19.9	1.4	0.64	87.36	10.38	1.62
Pepeekeo	5.7	77.2	16.0	1.1	0.41	92.62	6.73	0.24
Kohala (Hawi)	7.0	70.1	18.4	4.5	1.76	87.28	8.89	2.07
Kohala	4.9	73.1	18.8	3.2	0.80	87.35	8.65	3.20
Honomu	5.6	75.9	17.2	1.3	0.34	91.72	7.73	0.21
Kaiwiki	4.0	77.2	19.4	—0.6	0.95	89.03	9.32	0.70
Waimanalo	5.1	71.0	21.9	2.0	0.54	89.26	9.76	0.44
Kilauea	5.8	69.8	21.0	3.4	1.26	86.74	9.92	2.08
Waianae	4.8	78.3	14.6	2.3	0.36	92.00	5.95	1.69
Union Mill	5.2	75.3	15.7	3.8	0.44	90.25	7.09	2.22
Niulii	5.2	73.7	15.0	6.1	0.41	88.21	7.69	3.69

Factory	Cane Sucrose	MIXED JUICE		SYRUP		SUGAR	
		Sucrose	Gravity Purity	Gravity Purity	Increase in Purity	Sucrose	Sucrose per 100 Sucrose in cane
H. C. & S. Co.	15.76	12.04	89.22†	89.22	0.07	97.96	91.50
Oahu	13.45	11.27	87.09	87.94	1.16	98.10	92.83
Ewa	13.74	11.57	84.70	87.14	2.39	98.11	91.01
Waialua	14.02	12.39	86.0	87.4	1.6	98.13	91.31
Maui Agr.	15.74	13.23	87.79†	87.76	—0.28	97.81	92.28
Pioneer	14.16	12.12	85.17	86.58	1.72	97.82	89.90
Lihue	11.56	10.92	83.4	85.0	1.8	98.08	89.35
Olaa	12.07	11.02	86.3	88.0	1.9	97.86	90.12
Haw. Sug.	13.55	11.81	85.33	86.61	2.00	97.74	91.66
Kekaha	13.71	12.30	87.1	88.1	1.4	98.12	88.70
Honolulu	14.24	11.88	86.6	88.7	1.9	100.0	88.59
Haw. Agr.	11.56	10.49	86.62	87.24	0.62	97.92	87.76
Onomea	11.88	9.86	85.72	87.31	1.37	97.59	91.27
Hilo	11.79	10.92	85.51	86.68	1.22	97.53	90.47
Makee	10.79	9.58	81.37	82.63	1.15	97.83	86.42
McBryde	11.52	9.97	81.59	83.05	1.66	97.90	88.00
Wailuku	14.54	11.72	86.5	87.9	1.5	98.08	90.73
Hakalau	11.51	9.80	86.13	87.33	1.17	97.22	91.35
Kahuku	11.95	10.03	82.28	83.92	1.96	97.85	90.43
Laupahoehoe	12.85	11.36	88.27	88.88	0.72	98.16	91.48
Waiakea	12.92	11.18	86.1	87.87	1.80	97.86	90.32
Koloa	11.57	9.56	82.90	84.51	1.8	98.12	89.28
Hutchinson	12.00	10.36	84.41	85.97	1.69	97.60	91.42
Hamakua	13.04	12.52	85.00†	84.83	0.14	97.82	88.74
Paauhau	12.41	10.95	84.69	86.11	1.37	96.94	84.95
Pepeekeo	11.88	10.65	84.78	86.76	1.70	98.07	90.60
Kohala (Hawi)	12.77	11.93	81.66	83.65	1.98	97.95	84.95
Kohala	12.66	11.94	84.92	86.09	1.02	97.97	84.36
Honomu	11.26	9.32	84.73	86.10	1.85	98.01	89.61
Kaiwiki	13.13	12.06	87.33	88.13	0.91	97.91	85.64
Waimanalo	12.30	10.37	80.45	81.63	1.18	97.21	87.97
Kilauea	11.27	11.04	81.3	82.63	1.4	97.35	82.72
Waianae	14.17	12.30	86.64	87.80	1.30	98.05	89.70
Union Mill	12.51	11.32	84.79	85.87	0.99	97.45	85.84
Niulii	11.93	11.16	85.78	86.33	0.99	97.76	82.65
‡ True Average 1933	13.05	11.34	85.63	86.85	1.22	97.96	90.01
" " 1932	12.60	11.00	85.15	86.46	1.31	98.22	89.48
" " 1931	12.75	11.17	84.74	85.78	1.04	98.05	88.61
" " 1930	12.67	11.08	85.35	86.49	1.14	98.05	88.90
" " 1929	13.08	11.44	85.58	86.60	1.02	98.00	88.75
" " 1928	12.69	11.22	85.15	86.23	1.08	97.86	88.49
" " 1927	12.46	11.01	84.53	85.86	1.33	97.79	87.96
" " 1926	13.35	11.68	85.38	86.66	1.28	97.67	88.41

TABLE NO. 6—MILLING RESULTS

Showing the rank of the factories on the basis of milling loss.

Rank	1932 Rank	Factory	Milling Loss	Extraction Ratio	Extraction	Imbibition % Cane	Tonnage Ratio	Tonnage Fiber Ratio
1	1	Waimanalo.....	1.36	11.2	98.53	38.54	1.92	25.3
2	4	Onomea.....	1.65	13.9	98.31	39.80	2.24	27.2
3	2	Hakalau.....	1.69	14.7	98.27	35.52	1.90	22.3
4	3	Wailuku.....	1.86	12.9	98.51	41.46	1.31	15.1
5	6	Oahu.....	1.87	14.1	98.36	33.93	1.82	21.1
6	5	Hilo.....	1.91	16.3	97.85	28.35	2.10	27.7
7	12	Pepeekeo.....	2.06	17.4	97.81	30.39	1.90	23.9
8	17	H. C. & S. Co.	2.07	13.1	98.24	48.36	1.62	21.3
9	8	Ewa.....	2.07	14.5	98.12	39.76	1.81	23.5
10	15	Haw. Sug.....	2.09	15.7	98.01	34.04	1.84	23.3
11	10	Honomu.....	2.09	19.0	97.66	39.78	1.75	21.6
12	9	McBryde.....	2.09	18.4	97.54	35.18	1.50	20.0
13	7	Waialua.....	2.12	15.3	97.95	34.85	2.29	30.6
14	16	Pioneer.....	2.25	16.1	97.82	38.43	2.40	32.4
15	14	Kahuku.....	2.29	19.3	97.68	35.93	1.73	20.7
16	22	Waimea.....	2.31	17.3	97.83	34.04	1.71	21.5
17	20	Hutchinson....	2.37	20.0	97.71	33.18	1.91	21.9
18	19	Maui Agr.....	2.43	15.5	97.95	39.10	1.82	24.1
19	13	Paauhau.....	2.43	19.7	97.23	34.60	1.11	15.6
20	18	Koloa.....	2.44	21.5	97.50	38.30	1.47	17.0
21	25	Waiakea.....	2.49	19.6	97.46	36.24	1.88	24.3
22	11	Kohala (Hawi)	2.63	20.7	97.32	27.36	2.19	28.4
23	34	Makee.....	2.67	25.1	97.17	29.01	2.28	25.7
24	29	Honolulu.....	2.68	19.0	97.77	37.56	1.54	18.0
25	23	Laupahoehoe..	2.69	21.1	97.50	30.52	2.04	24.2
26	24	Olaa.....	2.72	22.6	97.22	29.09	2.52	31.0
27	21	Lihue.....	2.76	24.3	96.95	26.03	2.52	31.6
28	26	Haw. Agr....	2.88	25.3	97.16	28.09	2.06	23.1
29	30	Waianae.....	3.15	22.5	97.47	30.79	1.70	19.1
30	28	Kohala.....	3.17	25.1	96.56	26.92	1.71	23.4
31	31	Kekaha.....	3.22	23.8	97.16	29.46	2.38	28.4
32	27	Hamakua.....	3.53	27.4	96.48	25.04	1.45	18.6
33	32	Kilauea.....	3.98	35.6	95.32	21.65	1.68	22.1
34	33	Kaiwiki.....	4.13	31.8	96.16	26.19	1.69	20.4
35	36	Kaeleku.....	4.35	36.6	95.31	28.82	1.78	22.8
36	38	Union Mill	4.48	35.9	95.12	29.90	1.83	24.8
37	35	Honokaa.....	4.89	42.3	94.43	32.02	1.67	21.9
38	37	Niulii.....	5.66	47.7	93.65	26.02	1.89	25.2

TABLE NO. 7

True averages of factories basing control on mixed juice.

	1928	1929	1930	1931	1932	1933
First Expressed Juice—						
Brix	17.45	17.76	17.36	17.57	16.74	17.67
Purity	86.41	86.69	86.68	86.10	86.47	86.93
"Java ratio"	81.6	82.1	81.5	81.8	82.0	81.6
Mixed Juice—						
Brix	13.04	13.29	12.98	13.13	12.75	13.09
Purity	83.47	83.89	83.73	83.21	83.56	84.11
Weight % cane	109.87	110.18	109.77	110.28	108.62	111.00
Extraction	97.24	97.28	97.25	97.36	97.49	97.50
Extraction ratio	22.1	21.7	21.8	21.2	20.6	20.1
Last Expressed Juice—						
Pol	1.94	1.99	1.94	2.01	1.84	1.94
Purity	68.39	68.73	68.54	68.19	67.71	68.83
Imbibition water % cane.	31.99	32.44	32.15	32.23	32.59	33.11
Syrup—						
Brix	63.05	63.38	64.09	64.16	64.38	64.66
Purity	84.86	85.24	85.17	84.57	85.22	85.73
Increase in purity	1.39	1.35	1.44	1.36	1.66	1.62
Lbs. avail. CaO per ton cane	1.46	1.38	1.30	1.37	1.23	1.25
Filter Cake—						
Pol	2.34	2.27	1.82	1.65	1.20	1.14
Weight % cane	2.87	2.87	2.96	2.99	3.23	3.44
Pol % pol of cane	0.55	0.52	0.44	0.40	0.33	0.39

Filtration:

Cake pol (Table 7) is again the lowest on record. The amount of cake per cent cane has increased through larger use of screened bagasse as a filter aid, but the loss per 100 sucrose in cane is the lowest since 1920.

McBryde factory installed an Oliver-Campbell filter the past year and reduced cake pol from 1.87 to 0.48, and the loss per 100 sucrose in cane was reduced 57 per cent. Several factories have made moderate reduction in filter loses by the use of fine-screened bagasse added to the settlings before filter pressing.

Evaporation:

Syrup Brix at 64.98 is a new high record attained without any increase in reported evaporator equipment. The increase in the calculated amount of water evaporated per hour is 4.5 per cent over that of 1932.

Commercial Sugar:

After a gradual increase in sugar pol each year since 1919, the average dropped from 97.76 to 97.54. The reduction is due to the change in the Crockett Refinery contract. Factories in this group averaged 97.60 this year against 97.86 last year. The average for the other factories is 96.98, or .01 higher than in 1932.

TABLE NO. 8

LOW GRADE MASSECUITE WORK

Factories Listed in Order of Molasses Purity

Molasses Purity Rank			Molasses Gr. Pur. 1933	Factory	Remelt Ap. Pur. 1933	Remelt Purity Rank		
'33	'32	'31				'33	'32	'31
1	2	1	32.00	Kahuku	75.83	12	16	8
2	4	6	32.75	McBryde	77.73	6	7	6
3	9	10	32.82	Hutchinson	71.66	26	33	29
4	1	4	32.85	Koloa	73.5	18	24	20
5	7	9	33.07	Oahu	75.6	13	17	15
6	5	3	33.39	Ewa	75.28	14	12	10
7	6	11	33.40	Laupahoehoe	69.18	33	36	33
8	10	17	33.8	Lihue	70.4	29	29	16
9	8	5	33.94	Haw. Sug	78.13	5	6	3
10	17	8	34.14	Waianae	70.05	31	13	7
11	12	7	34.26	Pioneer	72.05	24	19	17
12	11	12	34.53	Pepeekeo	76.98	9	14	18
13	16	16	34.69	Waimanalo	68.88	35	34	32
14	38	..	34.77	Waimea	77.0	8	5	5
15	14	22	35.43	Waialua	71.14	28	23	23
16	3	2	35.46	Hamakua	72.77	21	15	13
17	20	26	35.64	Makee	72.88	20	35	27
18	13	13	35.69	Hakalau	72.43	23	27	30
19	21	15	36.01	Maui Agr	73.90	17	18	22
20	22	24	36.13	Hilo	74.4	16	25	24
21	25	18	36.13	Waiakea	71.3	27	26	31
22	15	14	36.61	Honomu	76.57	10	11	19
23	18	21	36.86	Honolulu	77.22	7	2	2
24	26	19	36.93	H. C. & S. Co	73.42	19	32	25
25	33	38	36.99	Union Mill	70.08	30	20	12
26	27	35	37.14	Kilauea	69.0	34	31	26
27	24	23	37.18	Onomea	78.65	4	8	9
28	30	29	37.22	Wailuku	71.9	25	22	28
29	19	20	37.42	Haw. Agr	74.57	15	10	11
30	23	34	37.44	Olaa	76.4	11	9	21
31	31	27	37.96	Kohala	66.25	38	37	34
32	29	30	38.03	Kekaha	69.3	32	30	35
33	28	31	38.29	Kohala (Hawi)	67.71	37	28	36
34	32	25	39.04	Honokaa	68.7	36	38	37
35	34	32	39.69	Kaeleku	79.55	3	4	4
36	37	36	41.15	Kaiwiki	80.78	2	1	1
37	35	37	42.08	Niulii	82.98	1	3	..
38	36	33	42.76	Paauhau	72.76	22	21	14

Averages	35.71	Year 1933	72.96
	35.90	" 1932	74.65
	36.32	" 1931	75.69
	36.69	" 1930	75.66
	37.02	" 1929	76.56
	37.39	" 1928	75.93
	37.59	" 1927	75.66
	37.97	" 1926	75.42

Final Molasses:

Molasses gravity purity has again decreased for the seventh successive year and new low records have been established for five years. The average is now 35.71. Kahuku, with an average of 32.00, again leads the list though their old record was 31.81 in 1927.

Table 8 lists the factories in the order of final molasses purity and also gives the relative rank for the two preceding years. Attention is called to the advancement of Waimea factory from last place to 14th with but minor changes in factory equipment. Other factories that have bettered their positions four places or more are Hutchinson, Waianae, Waiakea and Union Mill.

Niulii factory made boiling-house changes during a temporary shut-down near the close of the crop, which included the installation of several crystallizers. Excellent results were obtained on starting up, but the improvement hardly affects this year's Synopsis figures.

Remelt Sugar:

The average purity has dropped from 74.65 to 72.96, a lower figure than previously reported. While a lower purity final molasses can be temporarily obtained by turning out low purity remelt, the resulting increased duty put on low-grade equipment can hardly but result in higher average molasses purity.

Recovery

Boiling-house recovery increased by .58 to 92.67 and the overall by .61 to 90.43; both figures are better than in any previous year.

Analysis of the control figures indicates that the improvement in recovery over last year is about equally divided between better juice purity and improved factory work. The latter was obtained through better milling results and lower boiling-house losses. Calculations based on quality ratio bear out the same conclusions.

Comparison of Actual and Calculated Recoveries

In Table 9, factories are arranged in the order of the ratio of their recovery to that calculated. The basis for the first comparison has been changed this year, as previously stated, to 30 gravity purity molasses. The second comparison, now called Recovery Ratio, is on the same basis as before.

Calculations in this report have been made by Messrs. Brodie and Ashton, assisted by others of this department.

TABLE NO. 9

COMPARISON OF ACTUAL AND THEORETICAL RECOVERIES

Rank	Factory	Recovery Per Cent Calculated Recovery			Recovery Ratio†	
		Mill	Boiling House	Over All	Rank	Over All
1	Oahu	98.36	101.32	99.85	1	102.84
2	Haw. Sug.	98.01	101.05	99.26	3	102.20
3	Kahuku	97.68	101.15	99.00	2	102.50
4	Hutchinson	97.71	100.33	98.26	7	101.01
5	Maui Agr.	97.95	99.92	98.13	10	100.20
6	Ewa	98.12	99.32	97.64	8	100.58
7	Waialua	97.95	99.42	97.58	6	101.07
8	Koloa	97.50	99.65	97.42	12	99.85
9	Lihue	96.95	100.11	97.36	5	101.28
10	McBryde	97.54	99.53	97.33	4	101.52
11	Onomea	98.31	98.63	97.15	9	100.47
12	Hakalau	98.27	98.68	97.13	11	99.89
13	Waimanalo	98.53	98.14	96.87	13	99.77
14	Honomu	97.66	98.89	96.76	16	99.33
15	Wailuku	98.51	97.94	96.64	15	99.49
16	Pioneer	97.82	98.44	96.53	18	99.17
17	Pepeekeo	97.81	98.56	96.53	14	99.75
18	Waiakea	97.46	98.65	96.36	19	98.96
19	H. C. & S. Co.	98.24	97.86	96.32	20	98.94
20	Laupahoehoe	97.50	98.59	96.25	21	98.63
21	Hilo	97.85	98.09	96.17	17	99.30
22	Hamakua	96.48	98.87	95.80	29	96.38
23	Waianae	97.47	98.10	95.79	22	98.56
24	Olaa	97.22	97.76	95.31	23	98.44
25	Makee	97.17	97.78	95.31	26	98.00
26	Kaeleku	95.31	99.53	95.11	25	98.17
27	Honolulu	97.77	96.69	94.68	24	98.22
28	Kekaha	97.16	96.99	94.47	27	97.95
29	Haw. Agr.	97.16	96.95	94.39	28	97.32
30	Waimea	97.83	95.19	93.29	30	96.01
31	Kohala (Hawi)	97.32	94.54	92.26	31	95.53
32	Union Mill	95.12	95.69	91.29	33	93.72
33	Kilauea	95.32	95.09	90.92	32	94.34
34	Kaiwiki	96.16	94.31	90.85	34	93.51
35	Paauhau	97.23	93.13	90.78	37	92.57
36	Honokaa	94.43	95.54	90.49	36	92.96
37	Kohala	96.56	93.35	90.35	35	93.44
38	Niulii	93.65	94.37	88.66	38	90.90

* The boiling-house recovery is calculated on a basis of apparent purities of syrup and sugar corrected to the approximate gravity purities by adding .8 and .3 respectively, 30 gravity purity of molasses and no other losses.

The overall recovery is calculated in the same way except that the gravity purity of syrup is taken as the calculated apparent purity of normal juice plus .8, plus the increase in purity from mixed juice to syrup.

† The basis of this calculation is the reciprocal of cane ratio after correction to sugar ratio, with 98 extraction, syrup purity 1 less than the apparent purity of first expressed juice, sugar purity 98 (97.5 pol), gravity purity of molasses 33.3 and no other losses.